CORPS OF ENGINEERS, U. S. ARMY

MISSISSIPPI RIVER COMMISSION

WAVE ACTION AND BREAKWATER LOCATION
OSWEGO HARBOR, NEW YORK

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-291

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

MRC WES 200

JULY 1949

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*

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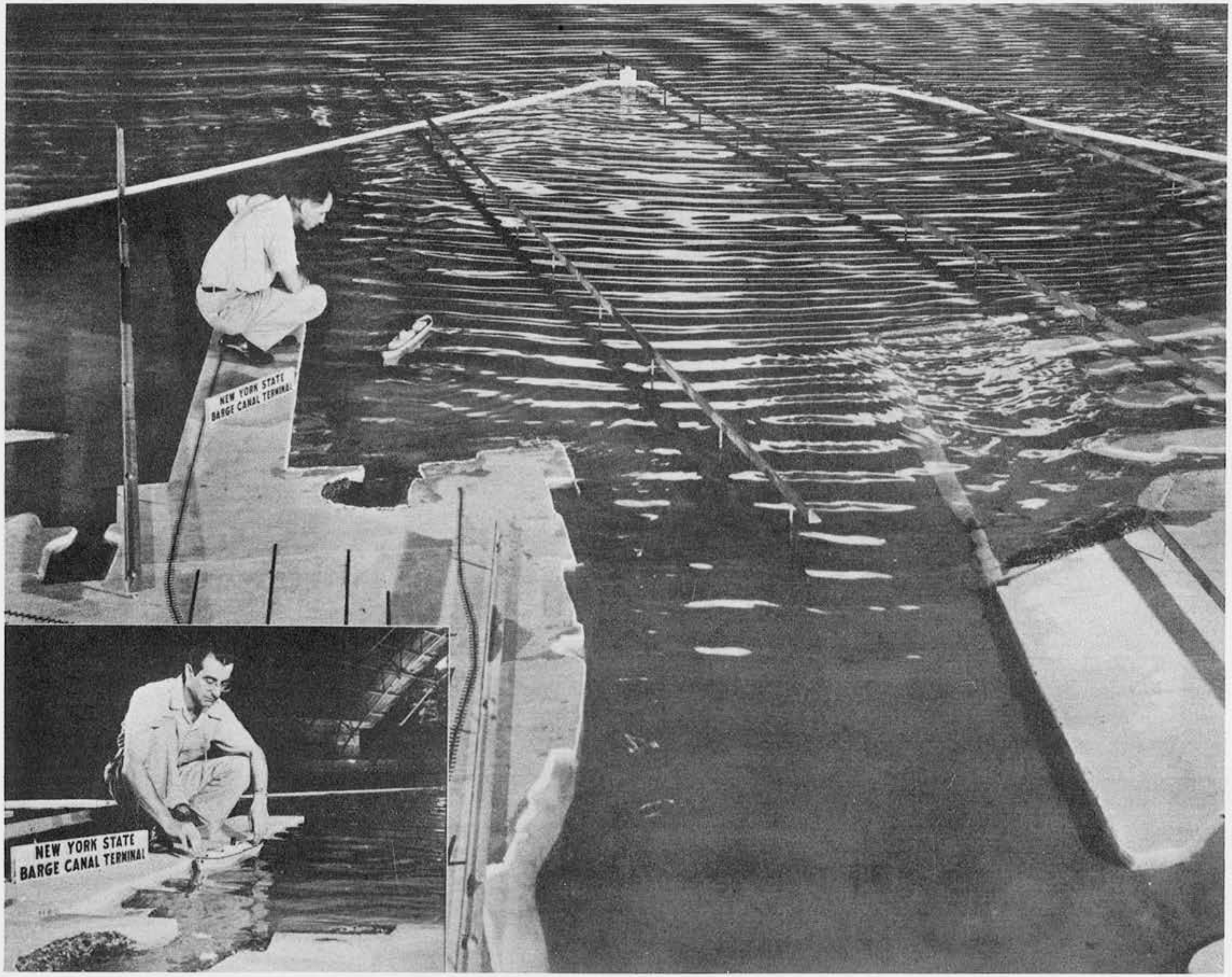
1. REPORT DATE **JUL 1949**	2. REPORT TYPE	3. DATES COVERED **00-00-1949 to 00-00-1949**
4. TITLE AND SUBTITLE **Wave Action and Breakwater Location, Oswego Harbor, New York: Model Investigation**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,Waterway Experiment Station,3903 Halls Ferry Road,Vicksburg,MS,39180**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**54**	



Model of Oswego Harbor, New York

PREFACE

Request for a model investigation of Oswego Harbor was initiated by the District Engineer, Buffalo District, in a letter dated 19 August 1947, and authority was granted by the Chief of Engineers in a second indorsement thereto dated 28 August 1947. Construction of the model was completed in February 1948 and the model tests were conducted during the period March to August 1948.

Liaison was maintained during the course of the investigation by means of progress reports and conferences. Prior to undertaking the investigation, an engineer of the Waterways Experiment Station visited the Buffalo District Office to confer with representatives of the District Engineer about the prototype problem and the model study. Personnel from the Great Lakes Division and the Buffalo District who, at various times, visited the Waterways Experiment Station to attend conferences and witness model demonstrations were Colonel H. D. Vogel, CE, District Engineer, Messrs. H. C. Woods, S. B. Hunt and W. L. Davis of the Buffalo District, and Messrs. E. W. Nelson, J. I. Thomas, W. E. McDonald and W. H. Booth of the Great Lakes Division. Engineers of the Waterways Experiment Station actively connected with the model study were Messrs. E. P. Fortson, Jr., F. R. Brown, R. Y. Hudson, and H. B. Wilson.

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SUMMARY

A hydraulic model investigation was performed of the harbor at Oswego, New York, to determine whether the proposed general plan of harbor improvement was adequate to protect the harbor from wave action, and if it were not, to devise a plan which would afford sufficient protection at minimum cost. The study was conducted using a concrete model geometrically similar to its prototype with a linear scale of 1:100. It was concluded from the results of the model study that: (1) the originally proposed breakwater plan would not be adequate to protect the harbor from wave action; (2) a breakwater plan developed during the model study, very similar to the originally proposed plan except for slight differences in length and alignment, would be satisfactory; (3) an artificial spending beach should be constructed at the southeast corner of the New York State Barge Canal Terminal; (4) an alternate breakwater plan developed during the model study would afford more effective protection from wave action than any of the other plans, but the cost of constructing this plan might be prohibitive; and (5) the existing impervious, vertical-walled wharfs in Oswego Harbor magnify the action of waves which gain entrance into the harbor through the navigation opening, making it desirable to avoid the construction of additional wharfs or other harbor structures of this type, unless the structures are to be located in harbor areas amply protected from wave action.

WAVE ACTION AND BREAKWATER LOCATION

OSWEGO HARBOR, NEW YORK

Model Investigation

PART I: INTRODUCTION

1. Oswego Harbor, Oswego, New York, is located on the south shore of Lake Ontario, about fifteen miles from its easterly end, at the mouth of Oswego River. The harbor is afforded some protection from storm waves by a system of converging rubble breakwaters which form a navigation opening 650 ft wide. The harbor area inclosed by the converging breakwater system is nearly 250 acres in size. A large portion of this area has been improved and is maintained at a project depth of -22 ft lwd (low water datum for Lake Ontario is 244.0 ft above mean tide at New York City). Plate 1 shows the existing breakwaters and shore-line structures within the harbor area.

2. The harbor is exposed to wind waves generated by storms from all directions between west and northeast. Storms occur most frequently from the directions west to northwest and, because of longer fetches in these directions, such storms usually generate the largest waves. However, because of the alignment of the existing navigation opening and the presence of an efficient spending beach on the east side of the inclosed harbor, the largest storm waves from the west-northwest directions do not cause intolerable wave-action conditions in the more important operating areas of the present harbor. Instead, storms which approach the harbor from the directions north-northwest to north-northeast are the most critical. Storms from these latter directions have caused considerable damage to

docks, delays in loading and unloading vessels, loss of cargo, and difficulty to ships maneuvering in the harbor.

3. Tentative plans for improving wave-action conditions in the harbor proposed a detached rubble breakwater 1000 ft in length aligned to protect the navigation opening, and thus the existing breakwater-inclosed harbor area, from storm waves from the north to northeast directions. The general plans of harbor improvement also included an east-harbor breakwater 4900 ft in length inclosing an area of about 80 acres for harbor expansion (plate 3). The proposed east-harbor breakwater, although included in the elements of the different breakwater plans tested in the model investigation, was not a cause for concern and consequently was not a part of the problem under study.

4. The model study was performed to determine whether the originally proposed breakwater would be adequate to protect the harbor from wave action during storms, and, if it were not, to devise a plan which would afford sufficient protection. It was desired to determine the breakwater plan which would provide optimum protection at minimum cost. It was believed also that the model would serve a very useful purpose in providing a visual aid in the understanding and integration of the complex and interdependent factors involved in the development of plans of harbor improvement.

PART II: THE MODEL

Design of the Model

5. Selection of the linear scale for the model was based on consideration of such factors as the required absolute depth of water in the model to prevent appreciable frictional resistance and surface tension effects, absolute size of the model waves, available shelter space, available wave-generating and measuring apparatus, cost of construction, and ease of model operation. Because of the effect of the depth-over-wave-length ratio on wave refraction for short-period waves, it was necessary to use a geometrically undistorted model (horizontal and vertical linear scales equal). After the linear scale had been selected the model was designed in accordance with Froude's[1] model laws. Based upon Froude's laws, a linear scale of 1:100 and a specific weight scale of 1:1, the following model-prototype relationships were derived:

Characteristics	Dimensions[2]	Model-Prototype Scale
Length	L	$L_r = 1{:}100$
Area	L^2	$A_r = L_r^2 = 1{:}10{,}000$
Volume	L^3	$\overline{V}_r = L_r^3 = 1{:}1{,}000{,}000$
Time	T	$T_r = L_r^{1/2} = 1{:}10$
Velocity	L/T	$V_r = L_r^{1/2} = 1{:}10$
Specific Weight	F/L^3	$\gamma_r = 1{:}1$

1 ASCE Manual of Engineering Practice, No. 25, "Hydraulic Models," p 9 & 43.
2 In terms of force, length and time.

Characteristics	Dimensions	Model-Prototype Scale
Unit Pressure	F/L^2	$P_r = L_r \gamma_r = 1:100$
Force	F	$F_r = L_r^3 \gamma_r = 1:1,000,000$
Weight	F	$W_r = L_r^3 \gamma_r = 1:1,000,000$
Energy	FL	$E_r = L_r^4 \gamma_r = 1:100,000,000$

Description of the Model

6. The model was a concrete structure 9100 sq ft in area which reproduced, to scale, all of the existing harbor area, about one-half mile of the Oswego River, and the shore line and shore-line structures from immediately west of the shore-end connection of the outer west breakwater to a point about 2800 ft east of the outer end of the east-arrowhead breakwater. Sufficient area of Lake Ontario north of the harbor was molded to the correct hydrography to insure proper reproduction of test waves from the west to northeast directions. Plate 1 shows the extent of the harbor and lake areas contained within the model limits.

7. A plunger-type wave machine[3] 60 ft in length was used to reproduce prototype waves to scale in the model. The model waves were reproduced in accordance with the same scale ratios as those used for model construction (paragraph 5). The waves were generated by the periodic displacement incident to the vertical and periodic movements of the plunger in water. The wave machine was mounted on rollers so that it could be moved to proper locations for generating waves from desired

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[3] For detailed description see Waterways Experiment Station TM No. 2-237, "Model Study of Wave and Surge Action, Terminal Island, San Pedro, Calif.", dated Sept 1947, p. 24.

directions. Figure 1 is a view of the model showing the wave machine in the background.

Fig. 1. General view of model; base-test conditions, 7-ft storm waves from north direction

8. Wave heights in the model were measured with a wave-height gage[4], or pick-up unit, in connection with a recording oscillograph. The wave-height gage consisted of series-connected resistors installed in a direct-current circuit with the resistors so calculated that the current varied directly with submergence of the gage in water.

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4 Ibid., p. 25.

PART III: THE TESTING PROGRAM

Selection of Test Conditions

Still-water level

9. All model tests in this investigation were conducted using a still-water level of +3.5 ft lwd. This selection was based on the average mean monthly level of Lake Ontario[5], which is +2.0 ft lwd, and an estimated value of 1.5 ft for the average effects of wind and seiche action on the local water level during storms. Thus, the value of +3.5 ft lwd represents an estimate of the average elevation of the water level for Lake Ontario, in the immediate vicinity of Oswego Harbor, during storms of such intensity and direction as to necessitate protection from wave action.

10. As shown by the Lake Survey records, the water level of Lake Ontario varies from year to year and season to season. The seasonal variation is more or less periodic, the highest lake levels occurring in the summer months. In addition to the seasonal variations, lake seiches are caused by sudden changes, or a series of intermittent-periodic changes, in atmospheric pressure and similar changes in wind speed and direction. In turn, the seiche oscillations cause periodic changes in local water levels (with periods ranging from a few minutes to a few hours) and relatively high surge currents in the harbor. Surges

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[5] "Monthly Mean Water Levels of the Great Lakes, 1860-1949". From official records of the U. S. Lake Survey, 630 Federal Building, Detroit, Michigan.

due to seiches are capable of causing troublesome, and sometimes damaging movements of vessels moored to piers in harbors. However, the problem at Oswego was considered to be due primarily to short-period wind (surface) waves and no attempt was made to reproduce seiche oscillations in the model for this investigation.

Wave dimensions and directions

11. Waves in deep water. As previously stated, Oswego Harbor is exposed to surface waves which are generated by winds blowing toward the harbor from the directions west to northeast. These limiting directions are determined by the shape of Lake Ontario and by the location of Oswego Harbor with respect to the lake shores (see plate 1). For the model investigation, the directions west, northwest, north-northwest, north, north-northeast and northeast were selected for use in ascertaining the relative advantages and disadvantages of the various improvement plans tested. The dimensions of wind waves in water of depth greater than about one-half a wave length are determined by the wind speed, wind duration, and the distance, or fetch, over which the wind blows. To insure that the advantages and disadvantages of each test plan are evaluated as accurately as possible, the relative frequency of occurrence in the prototype of the different waves used for testing should be known, and the model waves, propagated from the different directions of approach, should have the same relative dimensions as the corresponding prototype waves. The maximum waves which it is possible to generate from the major (quarter points of the compass) directions, according to formulae

derived by Stevenson[6] and to the theory of Sverdrup and Munk[7], using a wind speed of 50 knots, are as follows (fetch in nautical miles, wave height in feet, and wave period in seconds):

Direction	Fetch	Wave Height Stevenson	Wave Height Sverdrup & Munk	Wave Period
NE	17	6.6	12.2	5.2
N	30	8.4	17.0	5.9
NW	33	8.7	18.0	6.2
W	130	17.0	33.0	8.2

The theory of Sverdrup and Munk is thought to give wave heights too large for conditions of short fetch and high wind velocity. Wave periods given by this theory seem to be in good agreement with fact. Based on these premises, and giving more weight to the results obtained from Stevenson's formulae, the maximum storm waves which may approach Oswego Harbor are estimated to be more nearly as follows:

Direction	Wave Height (ft)	Wave Period (sec)
NE	7.0	5.2
N	9.0	5.9
NW	9.5	6.2
W	18.0	8.2

These maximum waves occur very rarely and, therefore, it would require an excessively long-term wind record to determine the relative frequency of occurrence for the different directions. The wind rose for Oswego

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[6] "The Design and Construction of Harbours, A Treatise on Maritime Engineering," by Thomas Stevenson. 3rd Ed., pp. 26-35. Adam and Charles Black, Edinburgh, 1886.

[7] "Revised Wave Forecasting, Graphs and Procedure," Wave Report No. 73, 1948, Scripps Inst. of Oceanography Univ. of Calif., La Jolla, Calif.

Harbor (plate 1) which was prepared by the Buffalo District, CE, from wind data for the period 1936-1945, indicates that wind with a speed greater than 25 mi per hr occurs with the following relative frequencies referred to the northeast direction:

Direction	Relative Frequency of Occurrence
NE	1
N	5
NW	17
W	12

The average wave dimensions resulting from storms with wind speed above 25 mi per hr are estimated to be as follows:

Direction	Wave Height (ft)	Wave Period (sec)
NE	5.0	5.0
N	7.0	6.0
NW	8.0	6.0
W	12.0	8.0

These values were used as deep-water waves in the testing of the different plans of harbor improvement. Where intermediate wave directions were used for testing, corresponding wave dimensions were obtained by interpolation. Thus, in the analysis of the model test results, the wave heights in the harbor for each plan and test-wave condition can be compared directly in determining the ability of each breakwater plan to protect the harbor against waves from the different directions. The over-all efficiency of each plan is determined from consideration of these wave height results in conjunction with the relative frequency of occurrence of the waves from different directions.

12. Waves in shallow water. As waves approach a shore over a

sloping beach, certain changes begin to take place in the wave height, length and direction of approach after the waves reach depths of water less than about one-half the deep-water wave length. When the waves feel bottom, the velocity of progress begins to decrease while the period remains constant. Therefore, the change in velocity appears as a decrease in wave length. Several wave lengths later, depending upon the slope of the beach, wave height begins to increase rather rapidly, and the wave length continues to decrease, until the wave becomes unstable and breaks. If a wave approaches a sloping beach at an angle, the portion nearest shore begins to slow down before the portion in deeper water. Thus, the wave front begins to curve toward the shore. Because of these facts, and since the Oswego Harbor model area was not extended into deep water (in order to reduce the cost of model construction), the wave heights, lengths and directions of approach of the test waves at the model wave machine were not the same as the corresponding wave heights, lengths and directions of approach of the selected deep-water test waves. After the deep-water test waves had been selected, as described in the previous paragraph, they were charted into the positions of the wave machine by wave-refraction diagrams[8], and the resulting wave dimensions and directions were generated in the model tests. The shallow-water wave characteristics which were reproduced on the model at the positions of, and by, the wave-machine plunger, compared with the corresponding deep-water waves, are shown below (D.W. = deep water; S.W. = shallow water):

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[8] "Breakers and Surf, Principles in Forecasting." H.O. No. 234, 1944. Issued by the U.S. Navy Department Hydrographic Office.

Direction		Wave Height		Wave Period	
D.W.	S.W.	D.W.	S.W.	D.W.	S.W.
NE	N 32° E	5.0	4.0	5.0	5.0
NNE	N 15° E	6.0	5.5	6.0	6.0
N	N 4° E	7.0	6.5	6.0	6.0
NNW	N 23° W	7.5	7.0	6.0	6.0
NW	N 46° W	8.0	7.5	6.0	6.0
W	N 85° W	12.0	10.0	8.0	8.0

Breakwaters

13. Since determination of the crown height of the proposed breakwaters was not one of the purposes of the model study, all tests were conducted with the crown of the model breakwaters arbitrarily raised to prevent overtopping. In this way the effects of different plans, and small changes in the elements of a particular plan, could be more accurately delineated. The prototype breakwaters will be of pervious rubble-mound construction. The model breakwaters reproduced the general shape of the prototype breakwaters but were constructed of concrete and were impervious. This was allowable because of the fact that the amount of wave energy which is transmitted through rubble breakwaters by short-period wind waves is insignificant.

Description of Plans Tested

Base-test conditions

14. The term "base test" is used in model investigations to denote tests conducted with the existing prototype conditions installed in the model. The purpose of these tests is to obtain basic data for use as a reference to which the results of tests of various proposed improvement plans may be compared. The prototype features used as base-test conditions

usually include, in addition to those elements existing in the harbor prior to the model study, any improvements contemplated or authorized which would be carried out regardless of the model study (improvements not related to or involved in the problems about which the model study is concerned). However, in this instance, the east-harbor breakwater, which had been authorized prior to the model investigation, was included in the elements of the plans tested rather than in the base-test conditions, because some of the plans involved changes in its length and alignment. Base-test conditions and the elements of all plans tested included the removal of shoals immediately in front of the existing navigation opening to a depth of -25 ft lwd. Figure 1 and plate 2 illustrate base-test conditions.

Plans A, B, B1, and E

15. Plan A was the breakwater plan of improvement originally proposed; its elements are listed in tables 1 and 2 and shown on plate 3. This plan consisted of a detached rubble breakwater 1000 ft long situated about 1040 ft[9] from the existing navigation opening with a straight alignment and a bearing of north 60° 45' west. Plans B and E were modifications of plan A. These plans were devised and tested to determine the elements of a plan similar to plan A which would afford maximum protection at minimum cost. The plan-B breakwater (see tables 1 and 2 and plate 4) was 650 ft long, and situated about 640 ft[9] from the existing navigation opening with a straight alignment and a bearing of north

[9] Measured from the center of the existing navigation opening to the nearest point on the center line of the breakwater.

75° 20' west. Plan B1 consisted of the elements of plan B with a spending beach at the southeast corner of the New York State Barge Canal Terminal (see table 1 and plate 19). The plan-E breakwater was 850 ft long and situated about 910 ft[9] from the existing navigation opening with a straight alignment and a bearing of north 75° 20' west (see tables 1 and 2 and plate 9).

Plan C

16. Plan C consisted of two detached breakwaters forming a wave trap or arrowhead type of protective works immediately north of the existing navigation opening. The western leg of this breakwater plan was 1110 ft in length with a bearing of north 16° 28' east, and the eastern leg was 970 ft in length with a bearing of north 46° 20' west. The elements of plan C are shown in tables 1 and 2 and on plate 5.

Plans D, D1 and D2

17. Plan D was an alternate type of protective works having two navigation openings and designed to utilize a portion of the east-harbor breakwater. This plan consisted of a detached breakwater 1550 ft long with a straight alignment and a bearing of north 47° 00' east. Plan D also involved the removal of about 330 ft of the north end of the existing east-arrowhead breakwater and the realignment and lengthening, by 410 ft, of the west end of the east-harbor breakwater (see tables 1 and 2 and plate 6). Plan D1 was tested as the ultimate development of plan D. In this plan the western navigation opening would be closed by extending the detached breakwater of plan D 750 ft to the north end of the existing west-arrowhead breakwater (tables 1 and 2 and plate 7). Plan

D2 was tested as a possible first step toward the development of plans D and D1. The detached breakwater of this plan would have the same alignment as that of plan D but the length would be reduced to 1100 ft. Plan D2 involved the realignment of the west end of the east-harbor breakwater, as in the case of plans D and D1, but the length of this portion of the breakwater would be reduced to 4800 ft. A portion of the north end of the east-arrowhead breakwater would not be removed as in plans D and D1. The elements of plan D2 are listed in tables 1 and 2 and shown on plate 8.

PART IV: TEST RESULTS

Test Data

18. Plates 17-24 show, graphically, wave data for each plan and direction of storm wave compared with comparable base-test data. The wave-height data on these plates were obtained at 21 selected wave-gage locations throughout the harbor area. Locations of these gages are also shown on plates 17-24. Plates 2-16 show test results by wave-height contours. These data are more comprehensive and are shown only for the most important wave directions (north and north-northwest). The north direction is the most important for base-test conditions (fig. 1), and north-northwest is the most critical direction for a majority of the plans tested.

Results of Tests

Base tests

19. The data obtained from tests with base-test conditions installed in the model, as shown on plates 2, 10, and 17-24, indicate that considerably more wave action results in the harbor when the waves are from the north. The second most critical direction is north-northwest. During severe storms from the north-northeast direction, the areas adjacent to the northeast ends of the Lackawanna Coal Dock and the New York State Barge Canal Terminal are subjected to fairly heavy wave action.

Plans A, B and E

20. Plans A, B and E are grouped for discussion because of their similarity. Plates 3, 4, 9, 11, 12, 16, 17, 18 and 24 present test

results of these plans. Plan A appeared to be satisfactory in protecting the harbor from waves from the north to northeast directions and would not increase action in the harbor due to waves from the northwest to north. However, the detached breakwater of plan A reflected westerly waves into the harbor, and, because of the size and frequency of occurrence of west waves, this condition would be intolerable. Plans B and E were designed and tested to determine a detached breakwater alignment which would provide sufficient protection from northerly waves and, at the same time, would not reflect westerly waves into the navigation opening. It was also necessary that the breakwater plan selected be satisfactory with respect to navigation requirements at the harbor entrance. Test results show that plan B would provide the best over-all protection to the harbor of any plan in this group. However, there is some question as to whether the navigation opening would be considered satisfactory by ships' masters. Plan E, which was a compromise between plans A and B, was devised to increase the navigability of the harbor entrance. Both plans B and E provided sufficient protection from waves from the critical directions without reflecting west waves into the harbor.

Plan B1

21. This plan consisted of the elements of plan B with a spending beach added in the southeast corner of the New York State Barge Canal Terminal. The test results shown on plate 19 indicate the efficacy of this plan. Table 1 shows the low rock yardage required to obtain this high degree of protection from wave action. The effectiveness of the spending beach is obscured by the fact that plan B provides such a high

degree of protection. However, numerous observation tests showed that the plan-B1 spending beach reduced wave heights 50 per cent or more in the area immediately north of the spending beach for base-test conditions and all plans investigated, and, by eliminating the standing wave system which originated at the vertical-walled corner of the New York State Barge Canal Terminal, caused wave action to be more tranquil over the harbor in general. The impervious vertical-walled piers in Oswego Harbor increase the degree of wave action by the formation of clapotis-type standing waves. Due to this fact, wave absorbers, judiciously positioned, can be a very effective means of reducing wave action in the critical harbor area.

Plan C

22. The arrowhead wave-trap form of detached breakwaters has been adopted at several harbors where added protection from waves is desired without the usual corresponding increase in entrance navigation difficulties. The results of tests on plan C, however (see plates 5, 13 and 20), show that in this instance the added arrowhead breakwaters would not provide adequate protection to the harbor. The failure of the plan-C breakwater to provide the desired degree of protection at Oswego Harbor is attributed to the effect of the shallow-depth contours, north of the existing navigation opening, on wave refraction. The hydrography of the lake area immediately north of the arrowhead breakwaters is such that wave refraction focuses wave energy on the navigation opening thus preventing normal expansion of the wave fronts after they have entered the arrowhead. The efficacy of this type of breakwater system is based

on the expanding of wave fronts (diverging orthogonals), and the consequent reduction in wave heights, between the two navigation openings of the arrowhead form of wave trap.

Plans D, D1 and D2

23. These breakwater arrangements were devised to provide, ultimately, the best possible wave protection and navigation entrance conditions. Plan D1 represents the ultimate development of this scheme, with plans D and D2 representing initial stages in its development. The results of plan D2 (the first stage in the ultimate development) compare favorably with those of plan E except for an increase in wave action in the area immediately east of wave gage number 15 (compare plates 23 and 24, 8 and 9, and 15 and 16). The second stage of construction, plan D, reduced the wave action in this area of the harbor to a satisfactory degree (plates 6, 14 and 21). Plan D1 provided practically complete protection to the harbor as well as space for an enlarged harbor (plates 7 and 22).

PART V: CONCLUSIONS

Conclusions

24. Based upon an analysis of the model test results, it is concluded that:

a. All plans tested, except plans A and C, would afford adequate protection to the harbor from storm-wave action.

b. Plan D1 would afford more protection to the harbor than any other plan tested. Next to plan D1, plan B1 would afford the most protection.

c. The spending beach feature of plan B1 should probably be adopted, regardless of the type of detached breakwater selected for construction, because of its effect in reducing wave action in the harbor at relatively low cost.

d. Navigation difficulties might be encountered by ships entering the plan-B harbor entrance during storms from the west, and by ships entering the plan-D and plan-D2 harbor entrances during storms from the north.

e. The impervious vertical-walled piers in the harbor tend to magnify the amplitude of waves which enter the harbor and impinge on the pier walls. Construction of additional vertical-walled impervious piers should be avoided, unless they are located in an area amply protected from wave action.

f. The plan selected for construction should be chosen from the following plans: B, B1, E or D1 (listed in order of construction costs). Without regard to costs, plan D1 should probably be selected. Selection of this plan would allow for a larger harbor area and would provide optimum protection with excellent navigation entrance conditions. If sufficient money were not available at present, plan D2 could be constructed first; later, plan D could be constructed; then at some future date, plan D1 could be completed. If this scheme is considered too ambitious, either plan B or plan E should be selected, depending on the judgment of competent navigators as to the difficulty of ships entering the plan-B opening during storms. If the plan-B opening is considered too dangerous, plan E should be selected.

TABLES

Table 1

LENGTHS AND VOLUMES OF BREAKWATERS TESTED

Plan	Breakwater Construction Length Ft	Breakwater Construction Gross Volume (1000 Cu Yd)	Breakwater Removal Length Ft	Breakwater Removal Gross Volume (1000 Cu Yd)
East Harbor Breakwater	4900	216.6	1030	50.7
A	5900	308.5	1030	50.7
B	5550	275.4	1030	50.7
B1	5550	282.3*	1030	50.7
C	6980	409.6	1030	50.7
D	6860	357.1	1360	80.9
D1	7610	413.8	1360	80.9
D2	5900	324.6	1030	50.7
E	5750	294.7	1030	50.7

* Includes spending beach at southeast corner of New York State Barge Canal pier.

Table 2

LOCATION OF PROPOSED BREAKWATERS

PLANE COORDINATES

Plan	Point Designation	Latitude (Ft) North	Departure (Ft) East	Departure (Ft) West
A	West end, detached breakwater	5,084.3		235.1
A	East end, detached breakwater	4,595.7	637.4	
B	West end, detached breakwater	4,545.0		311.0
B	East end, detached breakwater	4,380.4	317.8	
C	North end, west arm	4,912.0		752.0
C	South end, west arm	3,847.5		1,066.6
C	North end, east arm	5,074.0		81.0
C	South end, east arm	4,404.3	620.7	
D	West end, detached breakwater	4,381.2		225.7
D	East end, detached breakwater	5,438.3	907.9	
D	North end, east-harbor breakwater (relocated)	4,515.4	995.2	
D	Angle, east-harbor breakwater (relocated)	3,560.8	1,949.8	
D	Angle, east-harbor breakwater (relocated)	3,469.8	2,400.7	

Table 2 (Con'd)

Plan	Point Designation	Latitude (Ft) North	Departure (Ft) East	Departure (Ft) West
D	Angle, east-harbor breakwater	4,476.4	4,743.6	
D	East end, east-harbor breakwater	3,934.5	5,536.0	
D1	Junction, existing and proposed breakwaters	3,733.9		604.5
D1	Angle, proposed extension	4,381.2		225.7
D1	East end, proposed extension	5,438.3	907.9	
D1	North end, east-harbor breakwater (relocated)	4,515.4	995.2	
D1	Angle, east-harbor breakwater (relocated)	3,560.8	1,949.8	
D1	Angle, east-harbor breakwater (relocated)	3,469.8	2,400.7	
D1	East angle, east-harbor breakwater	4,476.4	4,743.6	
D1	East end, east-harbor breakwater	3,934.5	5,536.0	
D2	West end, detached breakwater	4,381.2		225.7
D2	East end, detached breakwater	5,131.4	578.8	
D2	North end, east-harbor breakwater	4,154.8	1,355.8	
D2	Angle, east-harbor breakwater (relocated)	3,560.8	1,949.8	

Table 2 (cont'd)

Plan	Point Designation	Latitude (Ft) North	Departure (Ft) East	Departure (Ft) West
D2	Angle, east-harbor breakwater (relocated)	3,469.8	2,400.7	
D2	East angle, east-harbor breakwater	4,476.4	4,743.6	
D2	East end, east-harbor breakwater	3,934.5	5,536.0	
E	East end, detached breakwater	4,600.6	539.8	
E	West end, detached breakwater	4,815.8		282.5
E, A, B and C	West end, east-harbor breakwater	3,124.2	1,083.6	
E, A, B and C	Angle, east-harbor breakwater	3,079.0	1,491.1	
E, A, B and C	East angle, east-harbor breakwater	4,476.4	4,743.6	
E, A, B and C	East end, east-harbor breakwater	3,934.5	5,536.0	

NOTE: Origin of coordinates is triangulation station "South Base" located at southeast corner of New York State Barge Canal Terminal.

PLATES

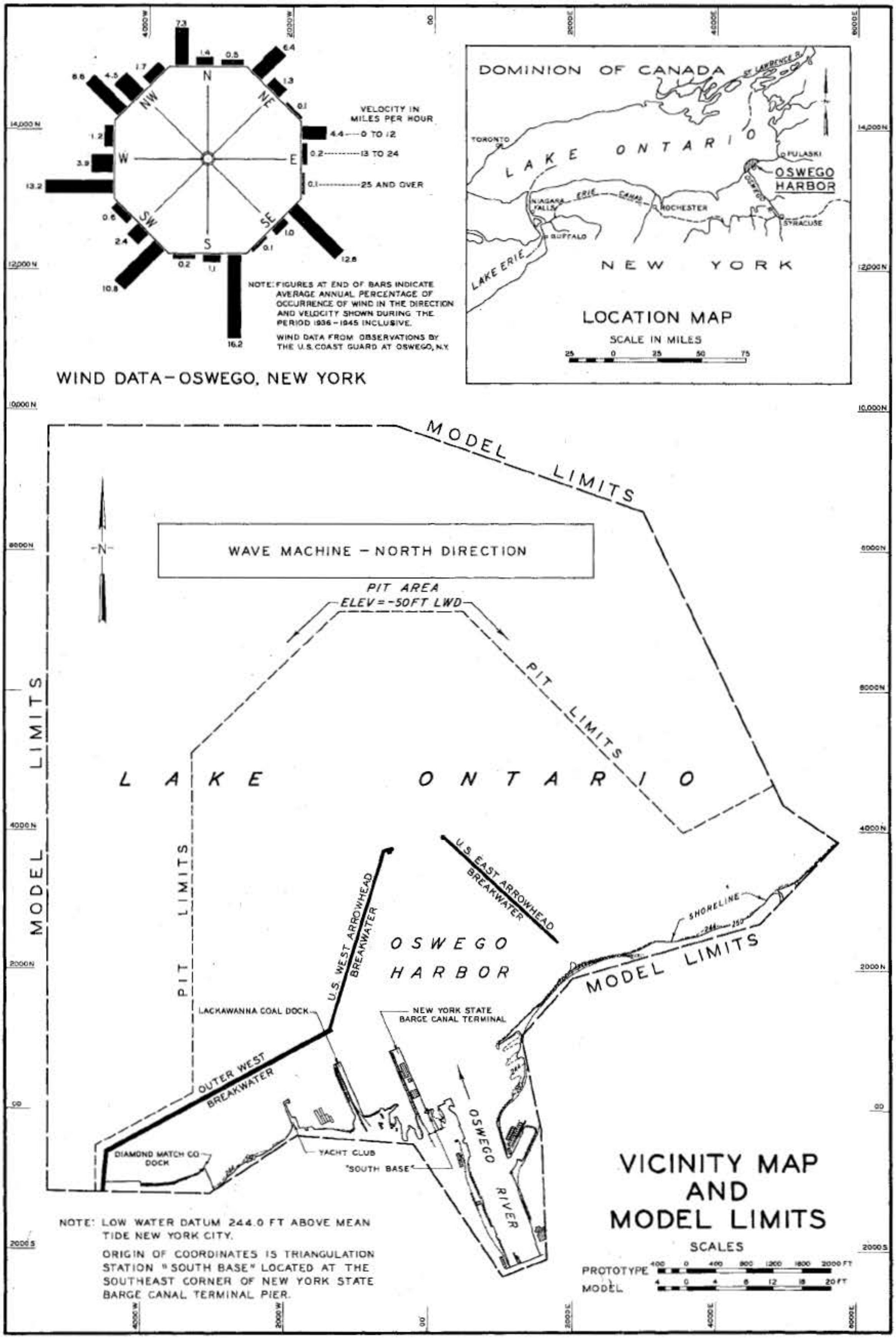
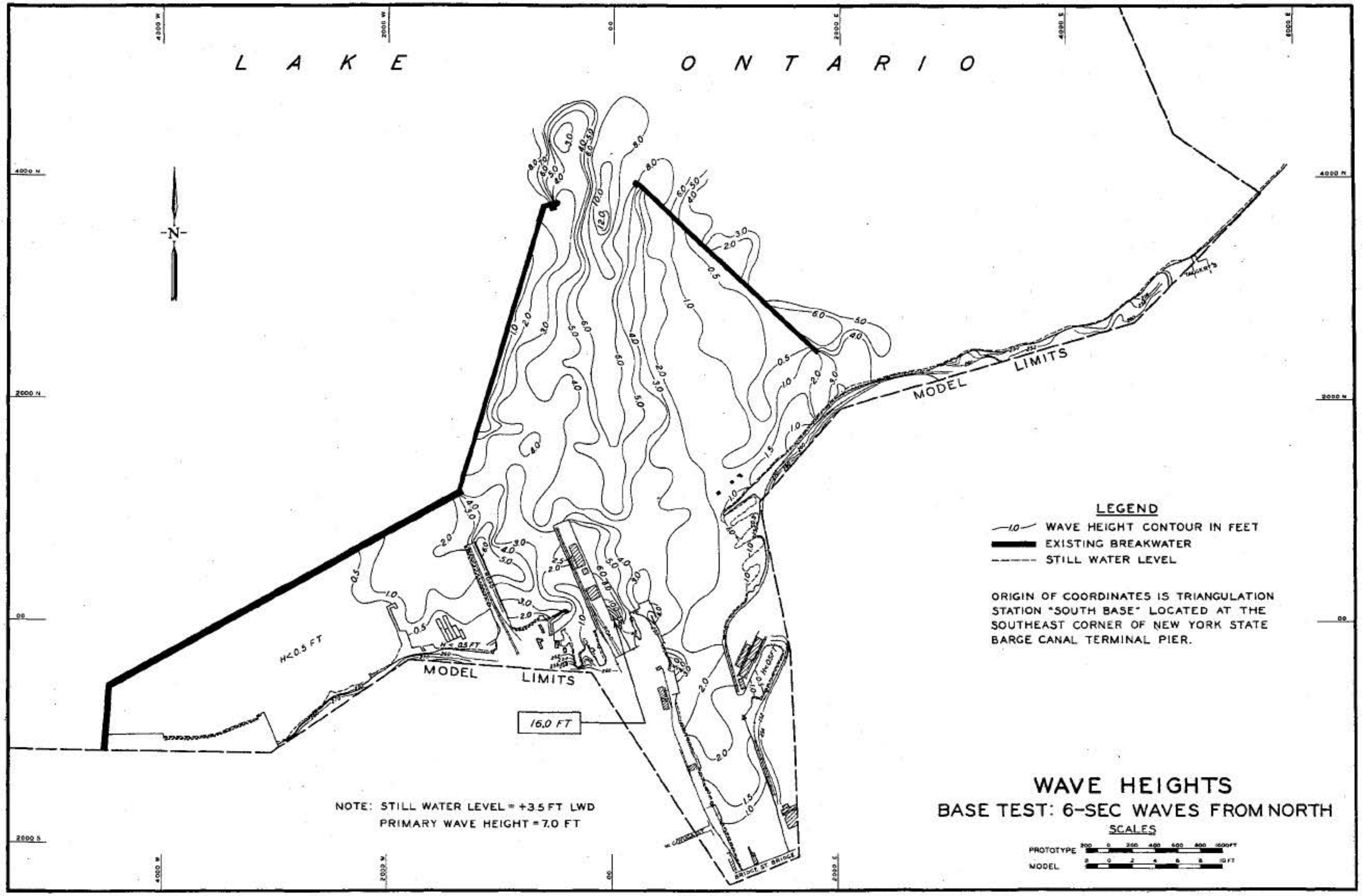

WIND DATA—OSWEGO, NEW YORK
VELOCITY IN MILES PER HOUR
0 TO 12
13 TO 24
25 AND OVER
NOTE: FIGURES AT END OF BARS INDICATE AVERAGE ANNUAL PERCENTAGE OF OCCURRENCE OF WIND IN THE DIRECTION AND VELOCITY SHOWN DURING THE PERIOD 1936–1945 INCLUSIVE.
WIND DATA FROM OBSERVATIONS BY THE U.S. COAST GUARD AT OSWEGO, N.Y.
N
NE
E
SE
S
SW
W
NW
DOMINION OF CANADA
ST LAWRENCE R.
TORONTO
LAKE ONTARIO
PULASKI
OSWEGO HARBOR
NIAGARA FALLS
ERIE CANAL
ROCHESTER
BUFFALO
SYRACUSE
LAKE ERIE
NEW YORK
LOCATION MAP
SCALE IN MILES
MODEL LIMITS
WAVE MACHINE — NORTH DIRECTION
PIT AREA
ELEV = -50 FT LWD
PIT LIMITS
LAKE ONTARIO
U.S. EAST ARROWHEAD BREAKWATER
U.S. WEST ARROWHEAD BREAKWATER
OSWEGO HARBOR
SHORELINE
LACKAWANNA COAL DOCK
NEW YORK STATE BARGE CANAL TERMINAL
OUTER WEST BREAKWATER
DIAMOND MATCH CO DOCK
YACHT CLUB
"SOUTH BASE"
OSWEGO RIVER
NOTE: LOW WATER DATUM 244.0 FT ABOVE MEAN TIDE NEW YORK CITY.
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
VICINITY MAP AND MODEL LIMITS
SCALES
PROTOTYPE
MODEL

PLATE 2


LAKE ONTARIO
-N-
LEGEND
1.0 WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
MODEL LIMITS
H<0.5 FT
16.0 FT
NOTE: STILL WATER LEVEL = +3.5 FT LWD
PRIMARY WAVE HEIGHT = 7.0 FT
WAVE HEIGHTS
BASE TEST: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL

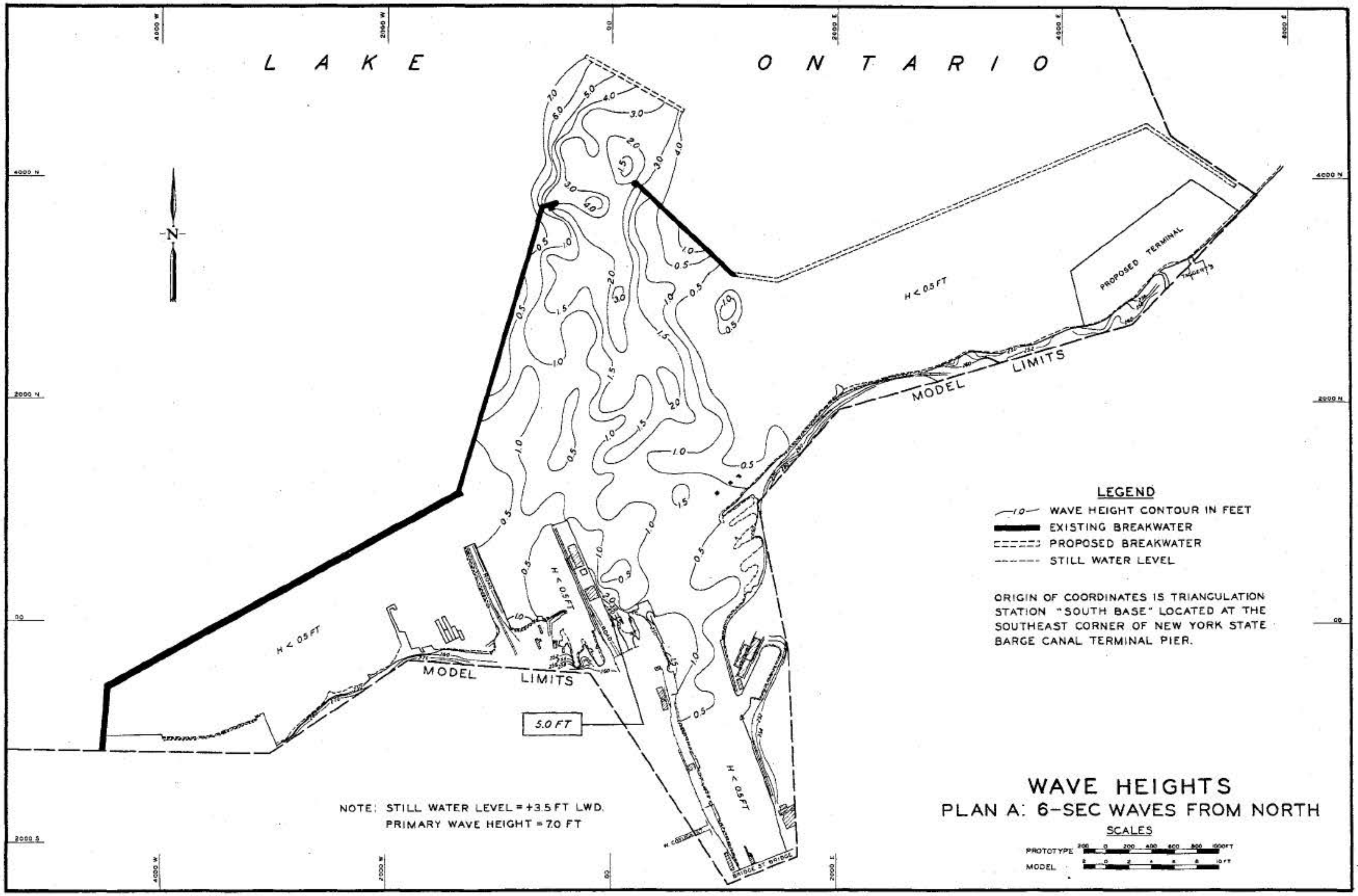
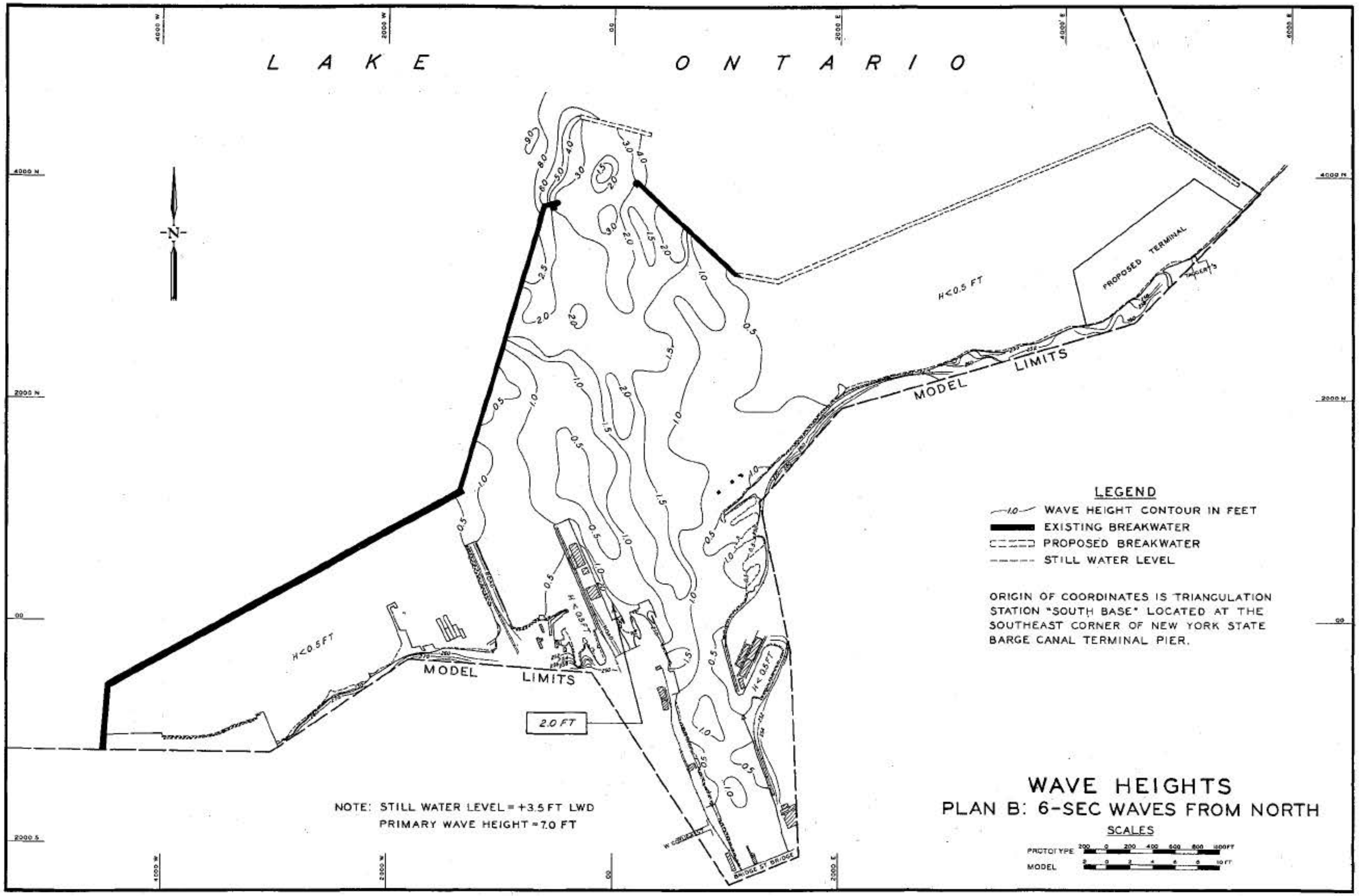

LAKE ONTARIO
H < 0.5 FT
PROPOSED TERMINAL
MODEL LIMITS
5.0 FT
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.0 FT
WAVE HEIGHTS
PLAN A: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE

PLATE 4



LAKE ONTARIO
LEGEND
1.0 WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
PROPOSED TERMINAL
H<0.5 FT
MODEL LIMITS
2.0 FT
NOTE: STILL WATER LEVEL = +3.5 FT LWD
PRIMARY WAVE HEIGHT = 7.0 FT
WAVE HEIGHTS
PLAN B: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE

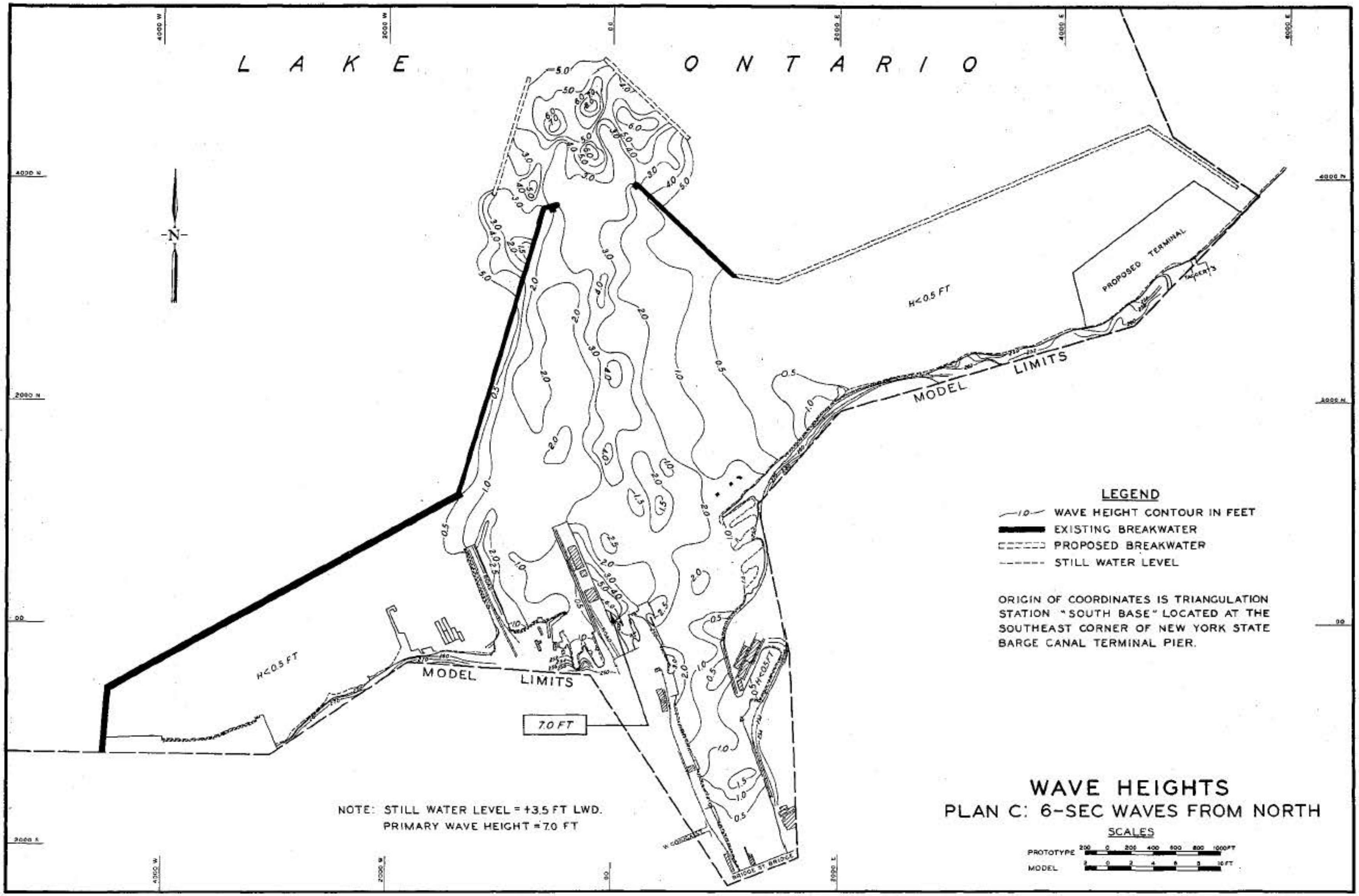
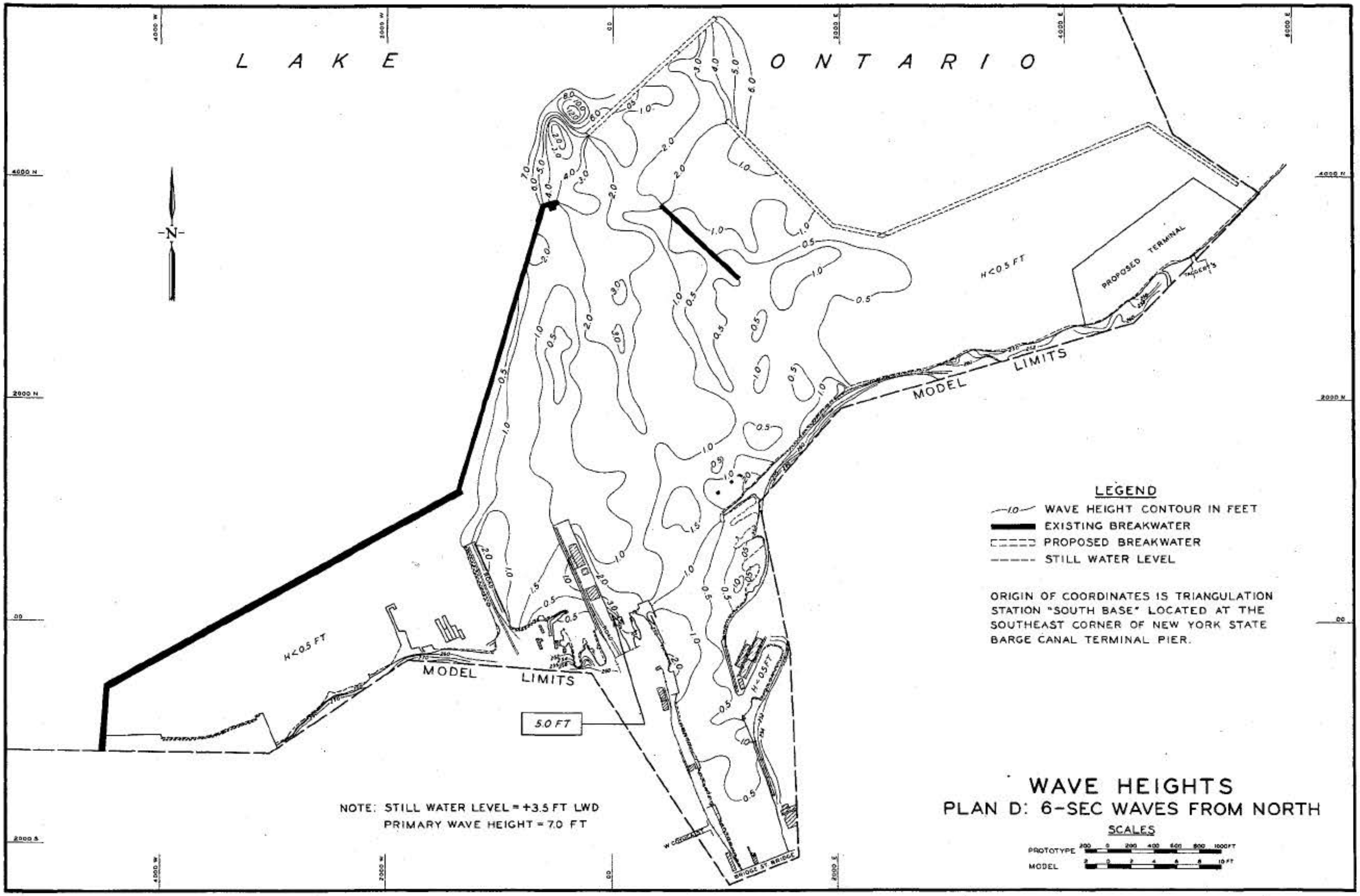
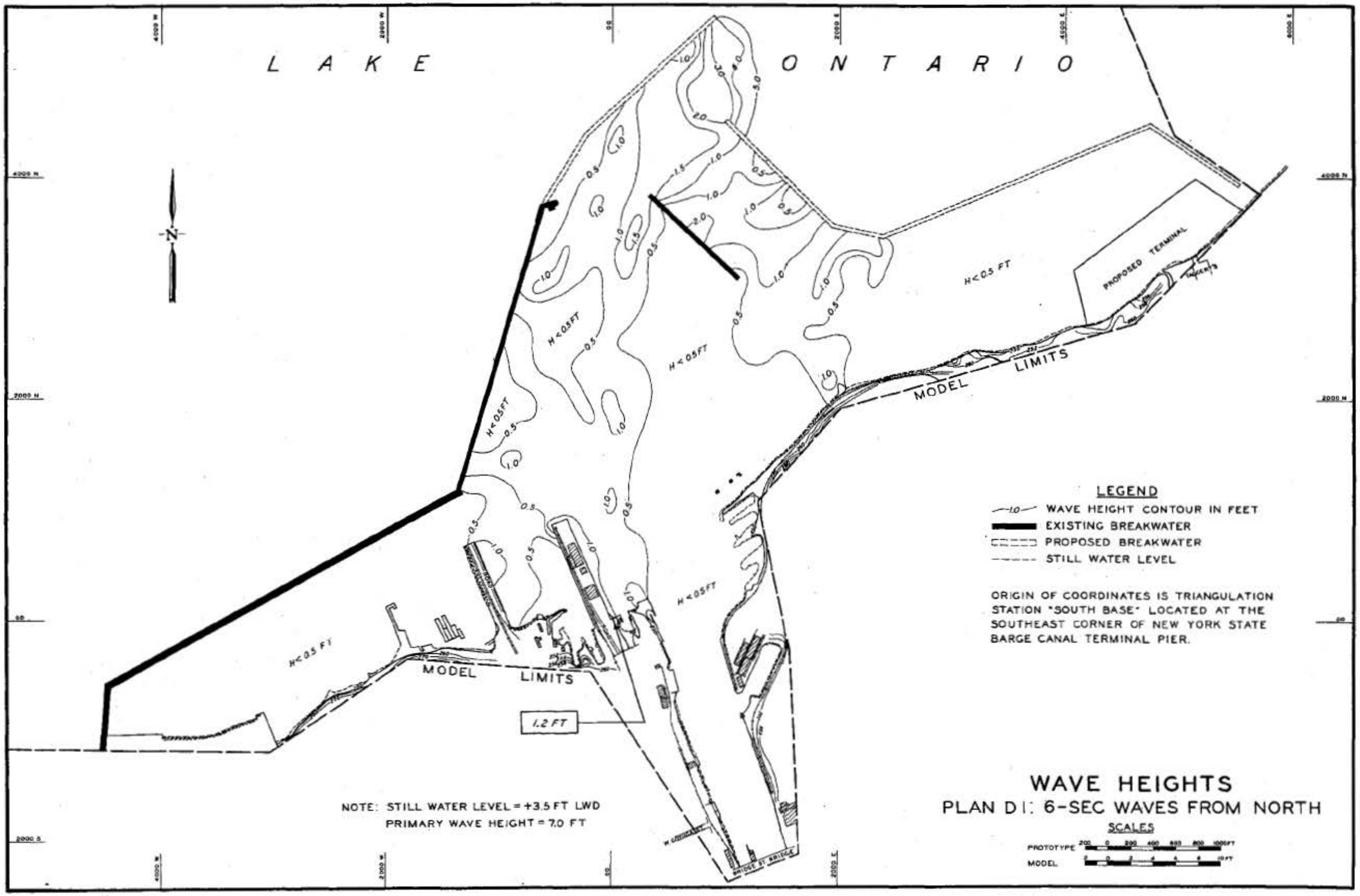

LAKE ONTARIO
H<0.5 FT
PROPOSED TERMINAL
MODEL LIMITS
7.0 FT
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.0 FT
WAVE HEIGHTS
PLAN C: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE

PLATE 5

PLATE 6

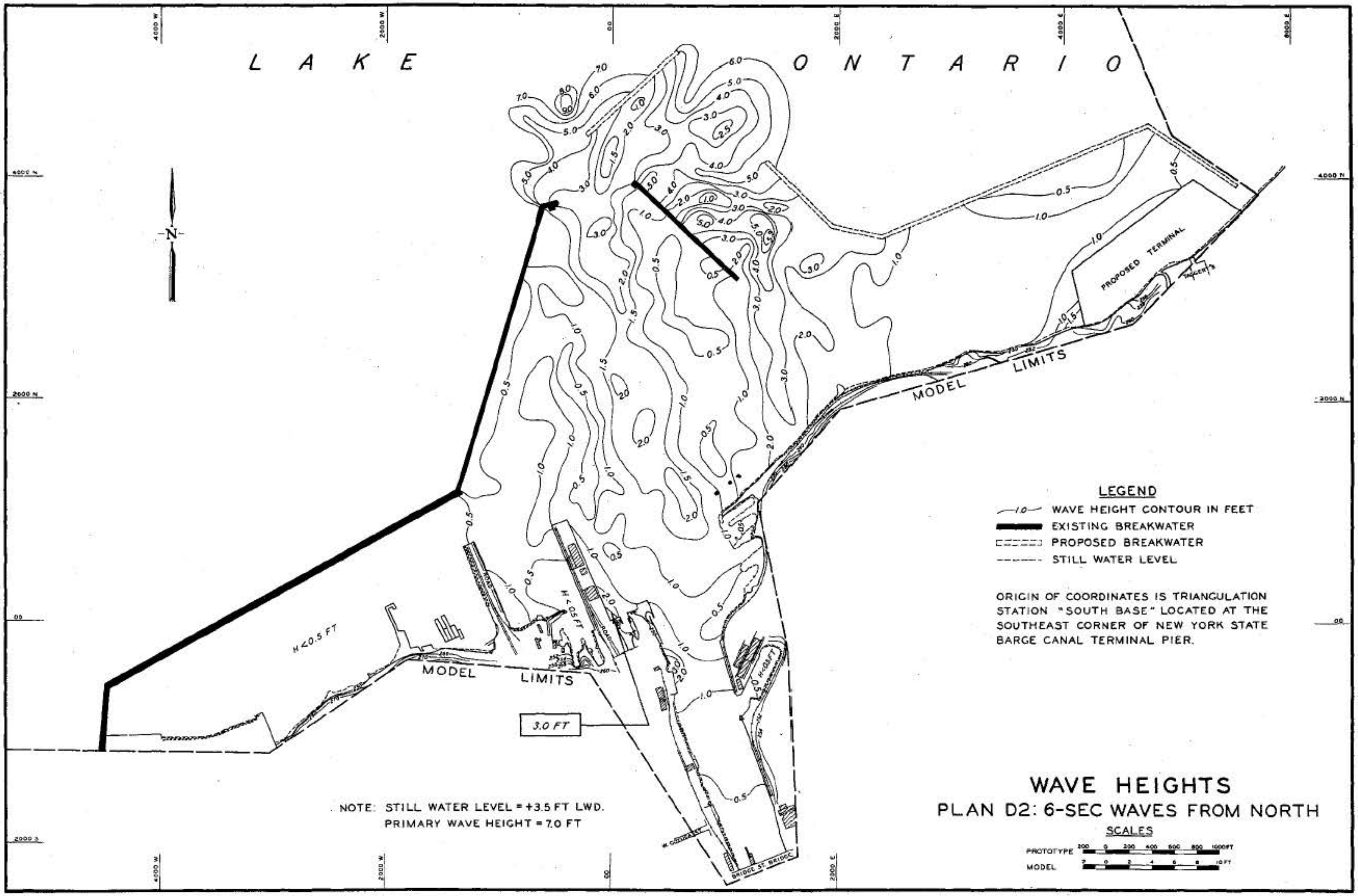


LAKE ONTARIO
LEGEND
1.0 WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
NOTE: STILL WATER LEVEL = +3.5 FT LWD
PRIMARY WAVE HEIGHT = 7.0 FT
MODEL LIMITS
H<0.5 FT
PROPOSED TERMINAL
5.0 FT
BRIDGE ST BRIDGE
WAVE HEIGHTS
PLAN D: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL



WAVE HEIGHTS
PLAN D1: 6-SEC WAVES FROM NORTH

PLATE 8


LAKE ONTARIO
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
PROPOSED TERMINAL
MODEL LIMITS
H<0.5 FT
H<0.5 FT
3.0 FT
BRIDGE ST. BRIDGE
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.0 FT
WAVE HEIGHTS
PLAN D2: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL

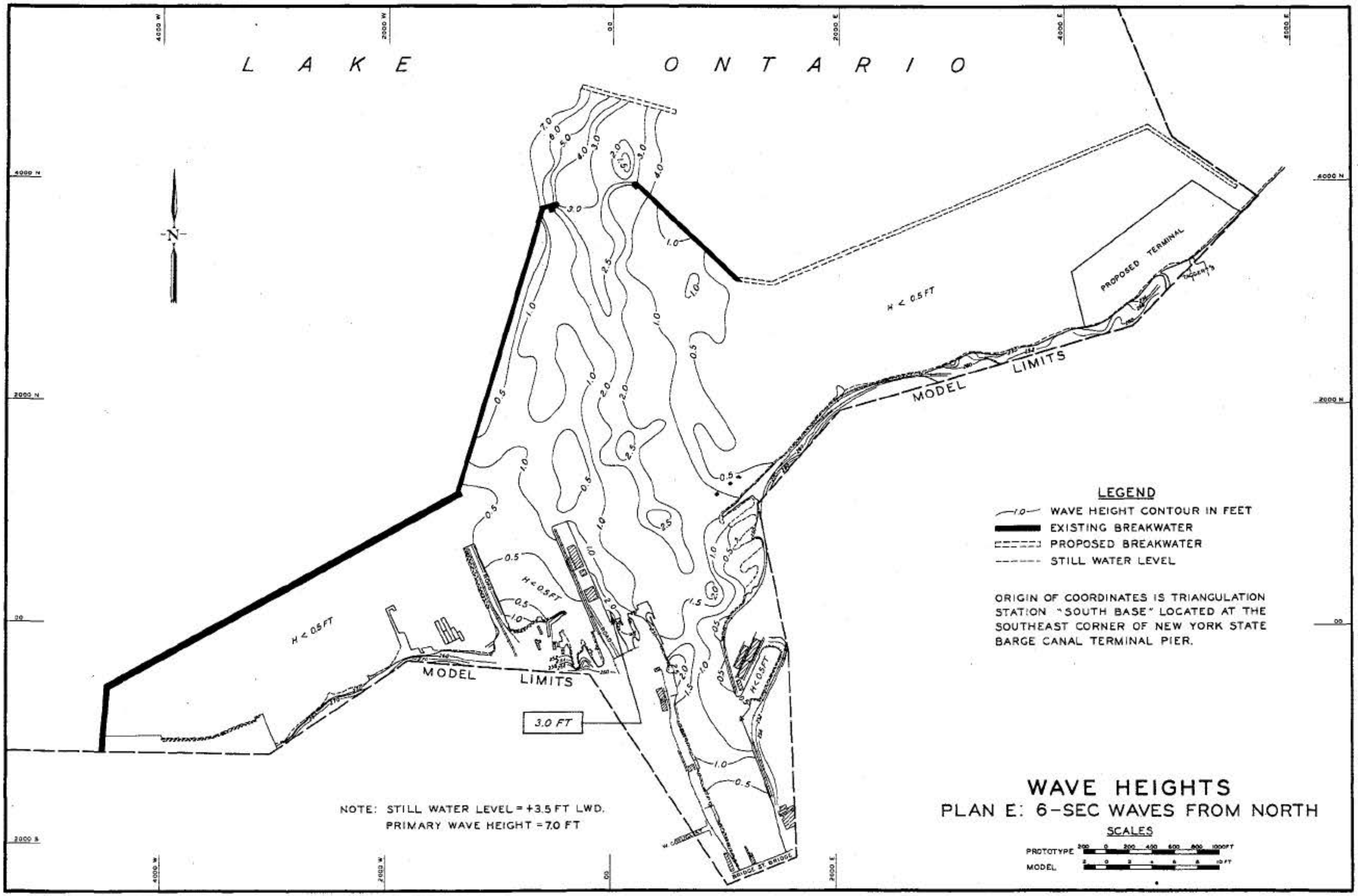
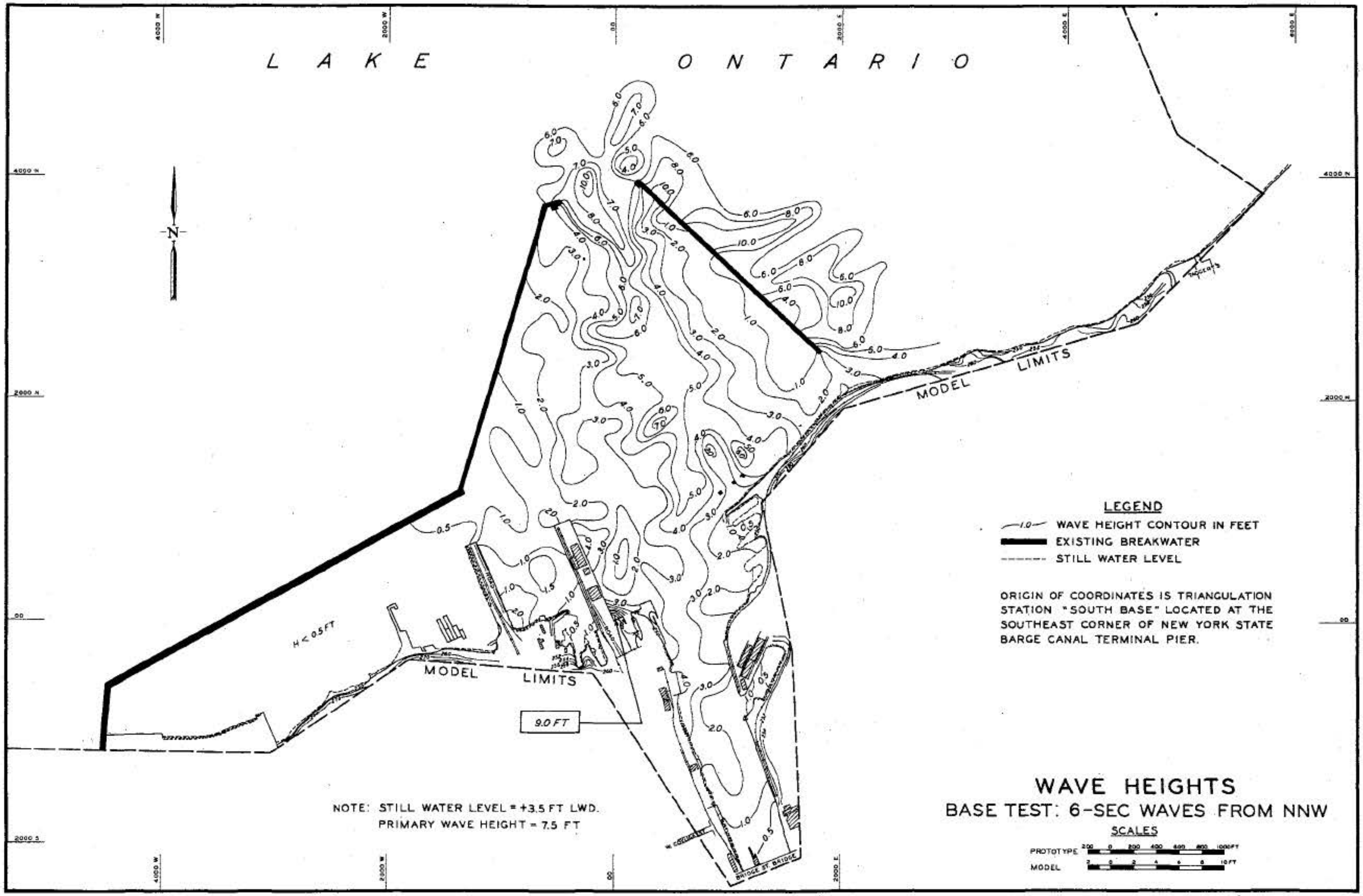

LAKE ONTARIO
LEGEND
1.0 WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
PROPOSED TERMINAL
H < 0.5 FT
MODEL LIMITS
3.0 FT
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.0 FT
WAVE HEIGHTS
PLAN E: 6-SEC WAVES FROM NORTH
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE

PLATE 9

PLATE 10



LAKE ONTARIO
N
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
MODEL LIMITS
MODEL LIMITS
H < 0.5 FT
9.0 FT
BRIDGE ST. BRIDGE
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.5 FT
WAVE HEIGHTS
BASE TEST: 6-SEC WAVES FROM NNW
SCALES
PROTOTYPE
MODEL

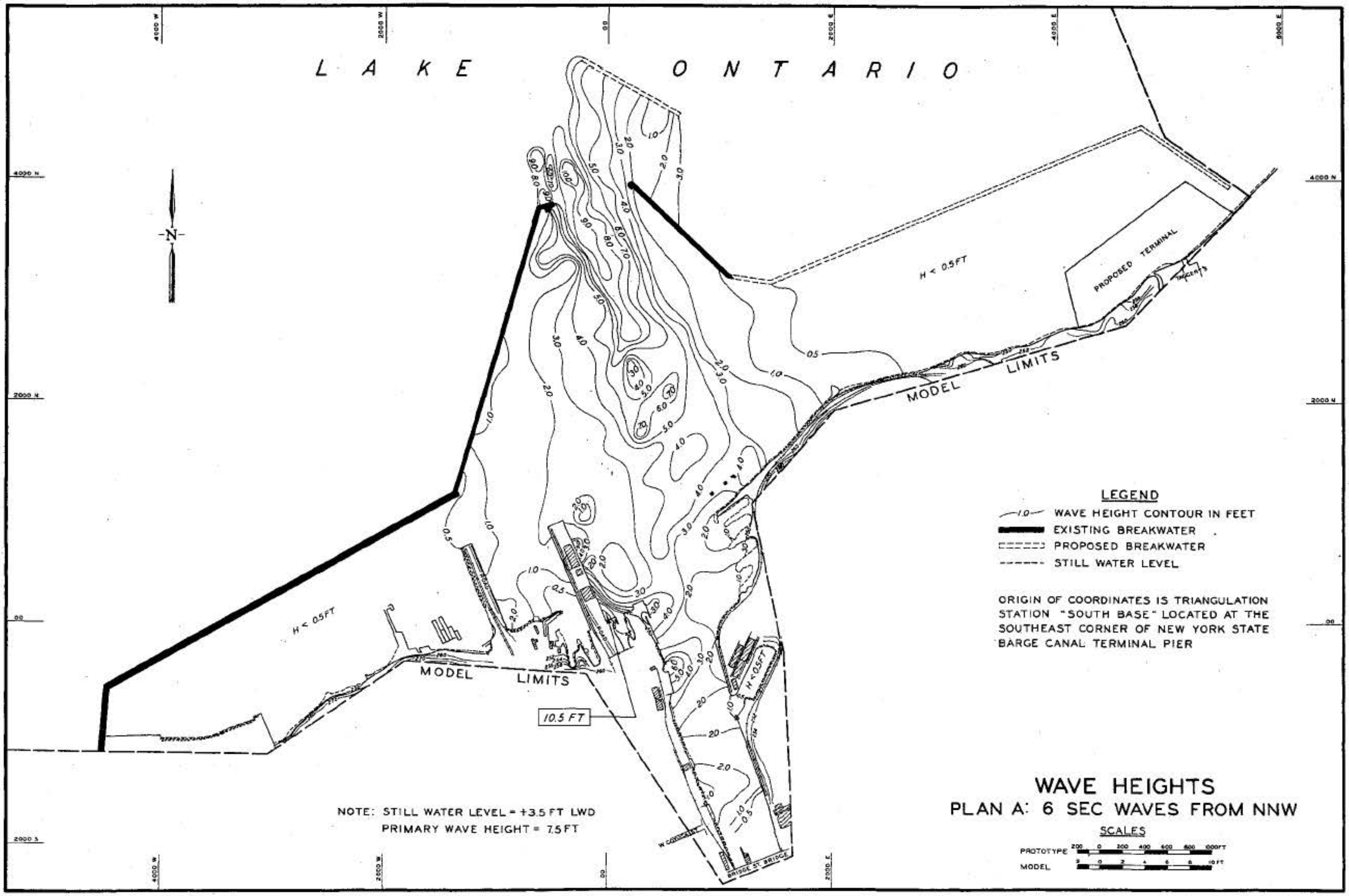
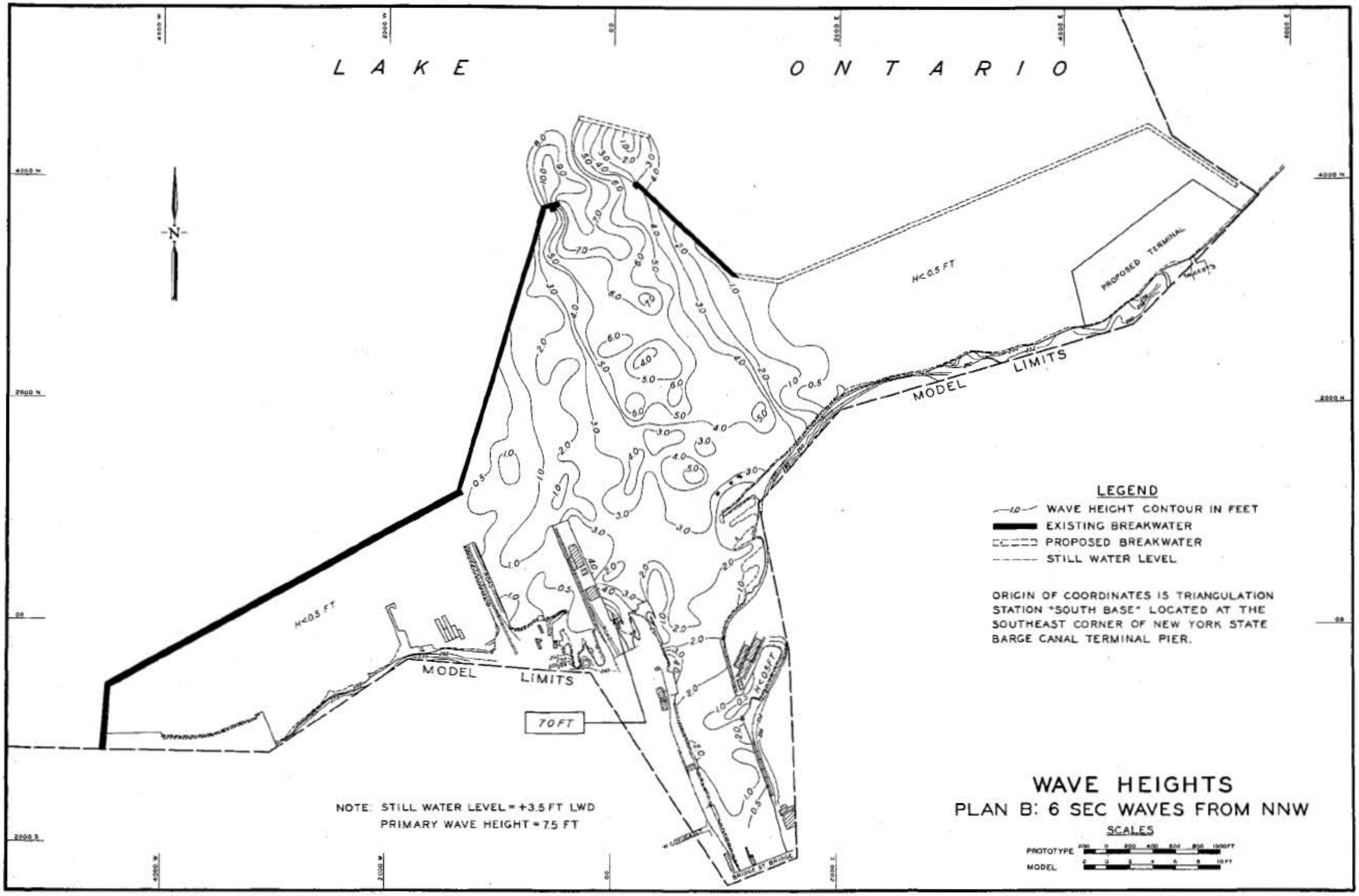
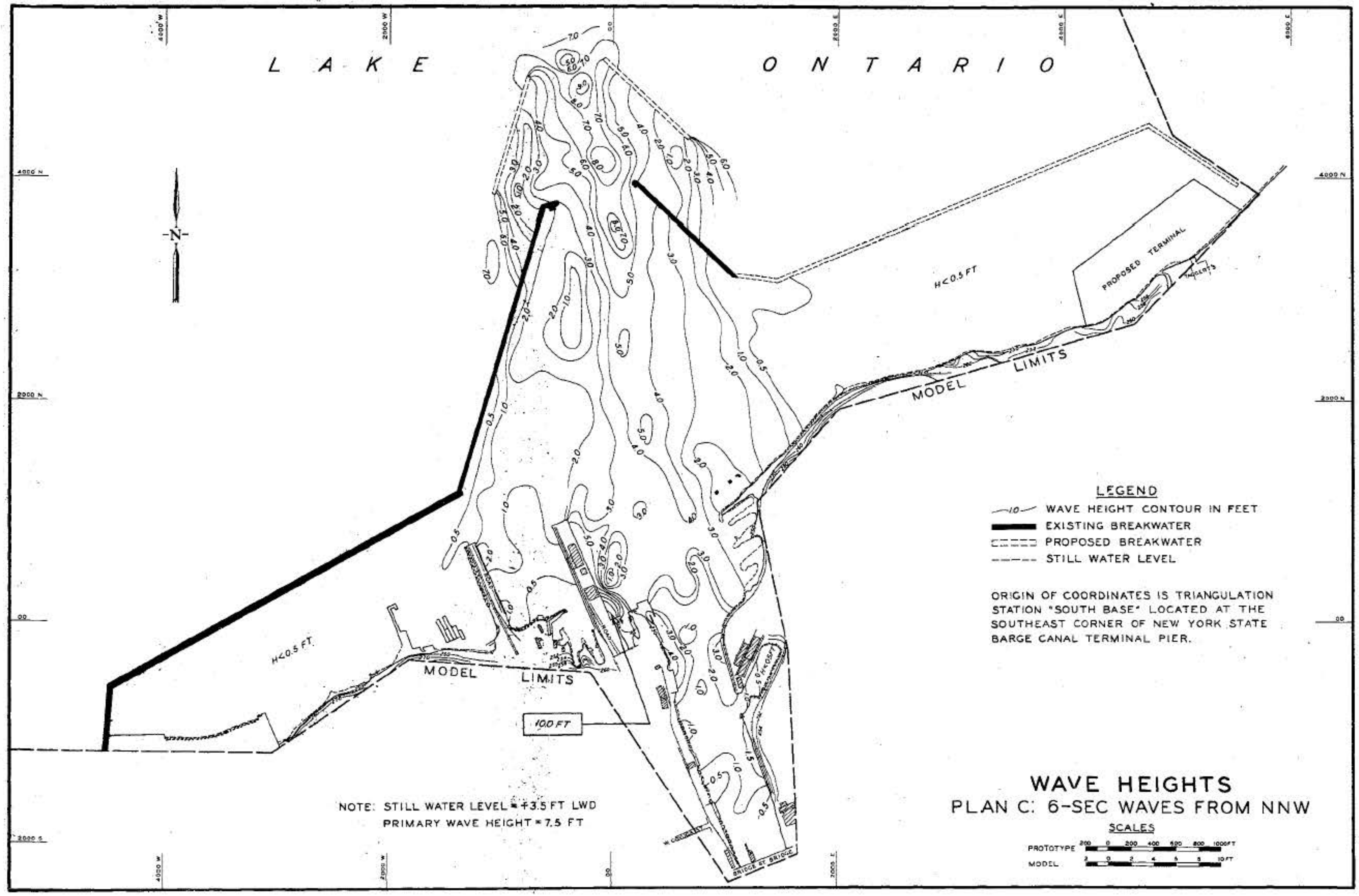

LAKE ONTARIO
H < 0.5 FT
PROPOSED TERMINAL
MODEL LIMITS
10.5 FT
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER
NOTE: STILL WATER LEVEL = +3.5 FT LWD
PRIMARY WAVE HEIGHT = 7.5 FT
WAVE HEIGHTS
PLAN A: 6 SEC WAVES FROM NNW
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE

PLATE 11

PLATE 12

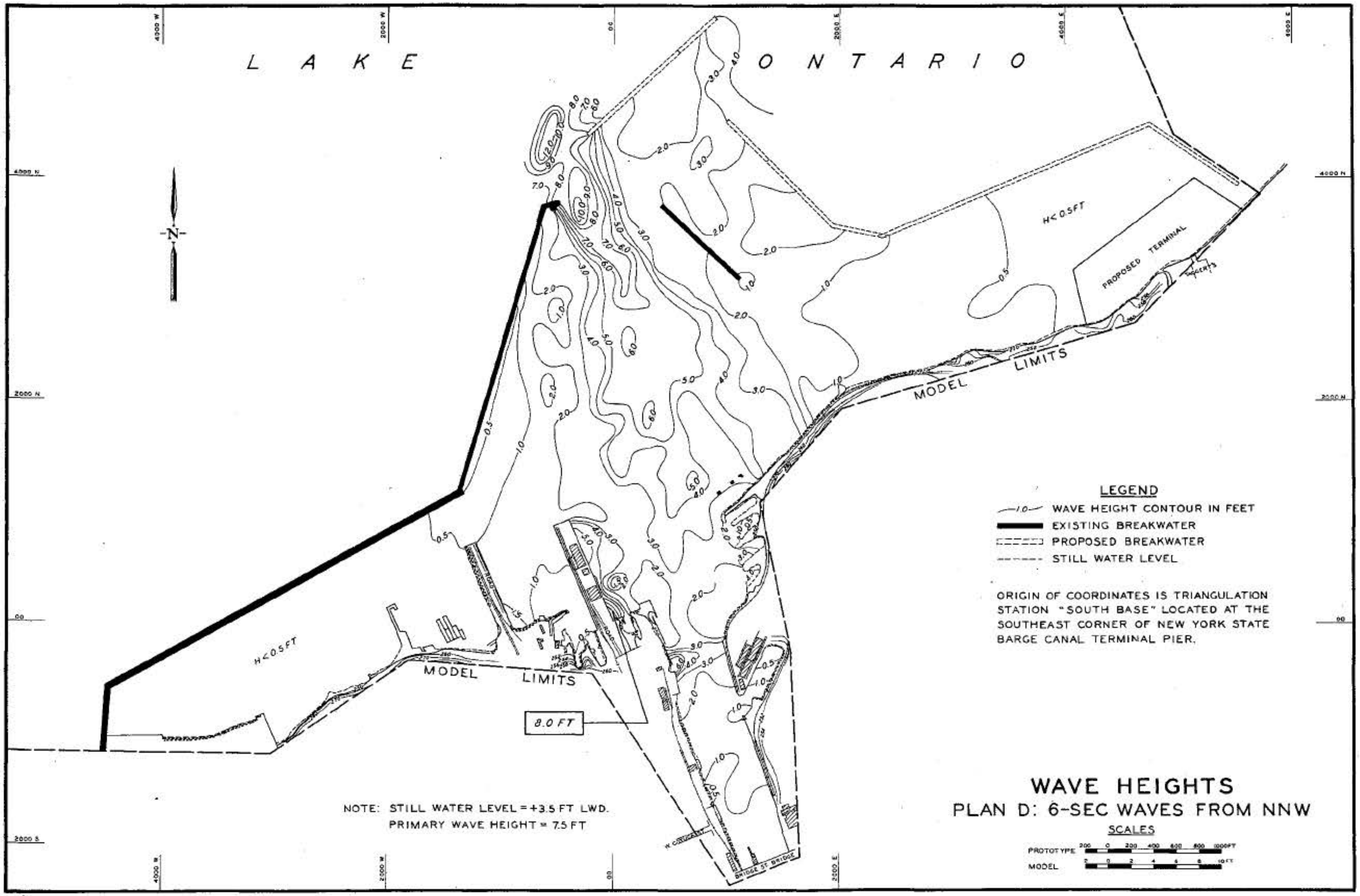

L A K E O N T A R I O
N
H<0.5 FT
PROPOSED TERMINAL
MODEL LIMITS
MODEL LIMITS
70 FT
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
NOTE: STILL WATER LEVEL = +3.5 FT LWD
PRIMARY WAVE HEIGHT = 7.5 FT
WAVE HEIGHTS
PLAN B: 6 SEC WAVES FROM NNW
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE



WAVE HEIGHTS
PLAN C: 6-SEC WAVES FROM NNW

PLATE 13

PLATE 14


L A K E
O N T A R I O
H< 0.5 FT
PROPOSED TERMINAL
MODEL LIMITS
MODEL LIMITS
H< 0.5 FT
8.0 FT
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.5 FT
WAVE HEIGHTS
PLAN D: 6-SEC WAVES FROM NNW
SCALES
PROTOTYPE
MODEL
BRIDGE ST BRIDGE

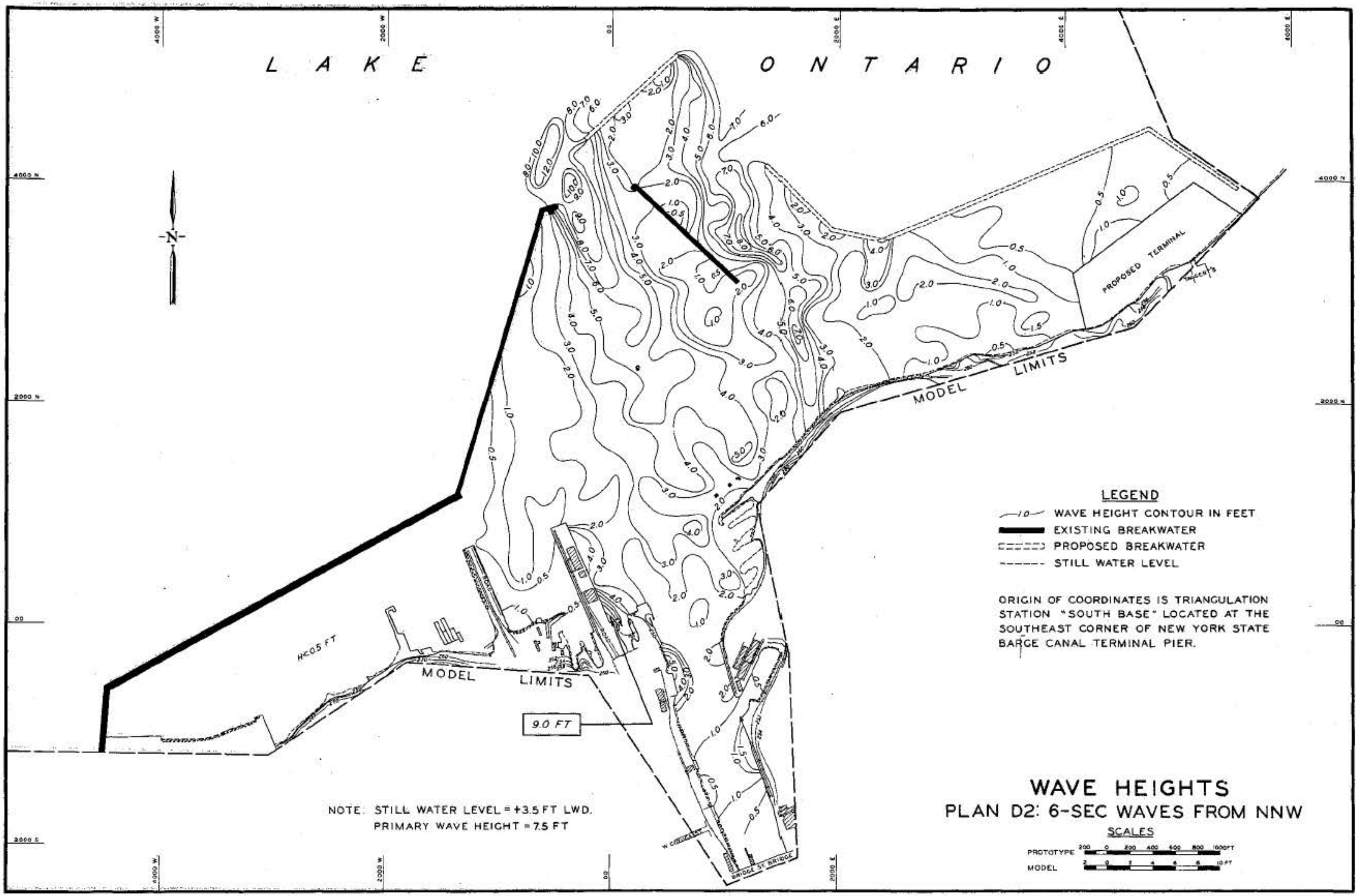
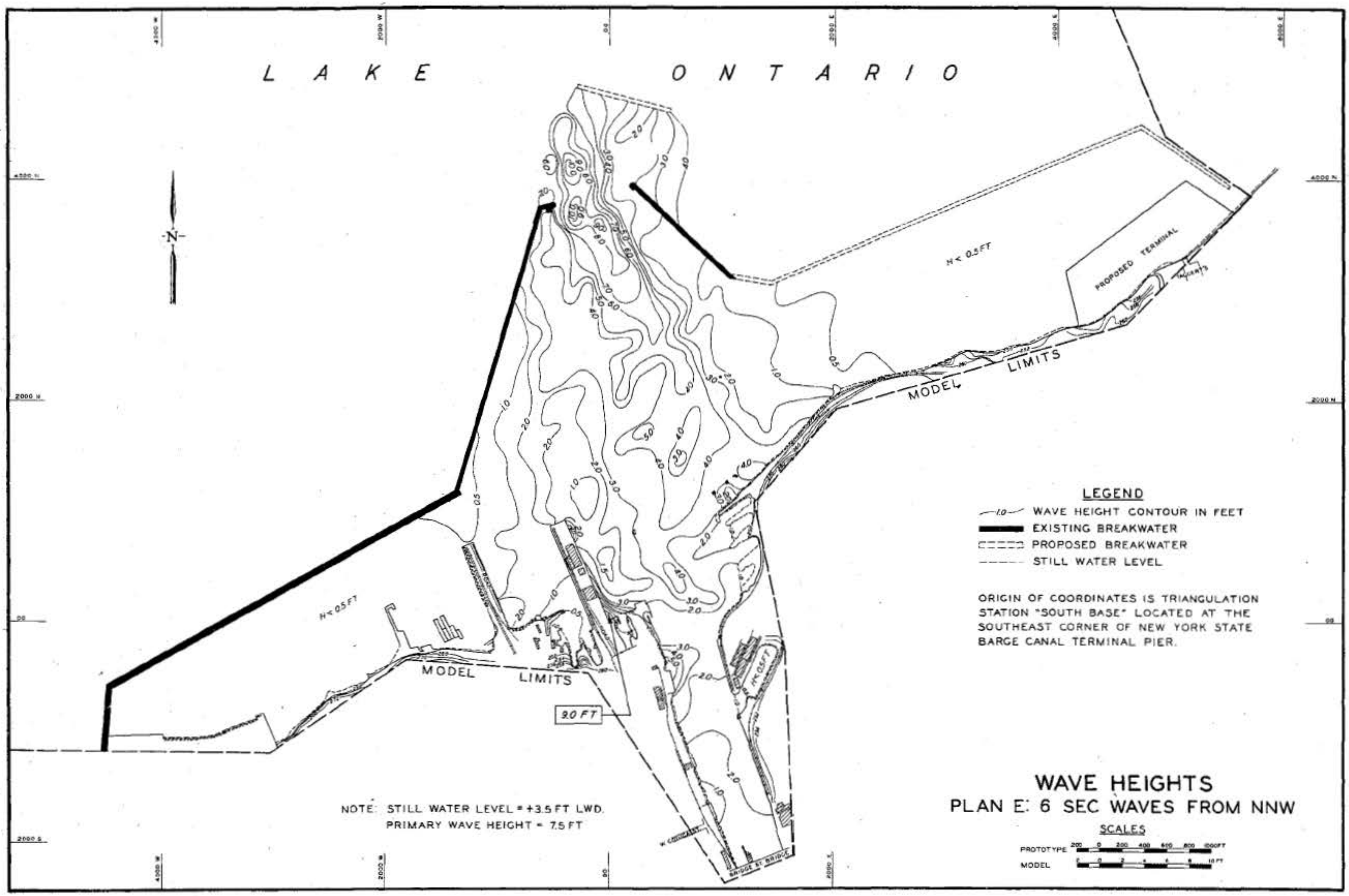
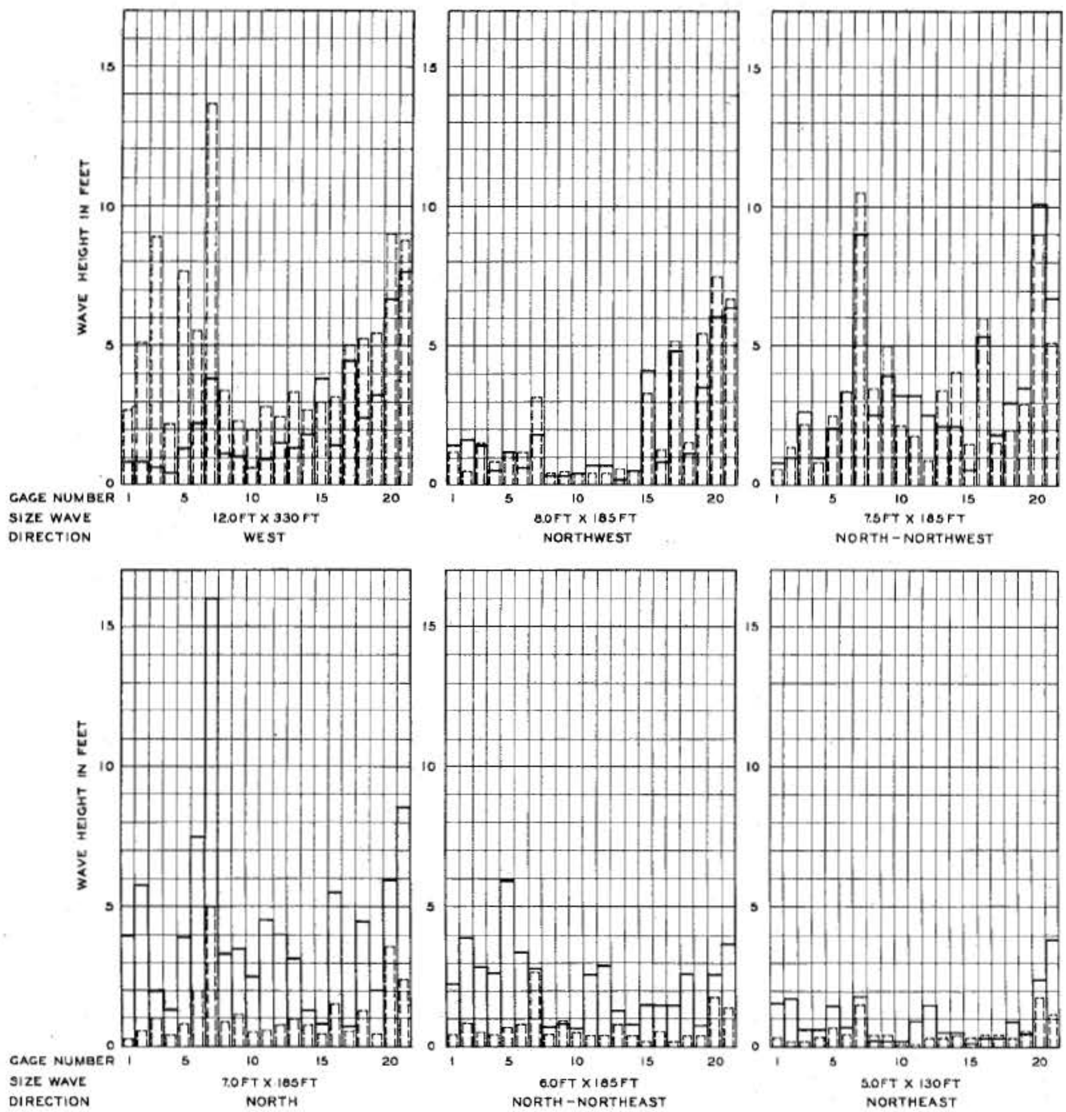

LAKE ONTARIO
MODEL LIMITS
MODEL LIMITS
PROPOSED TERMINAL
H<0.5 FT
9.0 FT
BRIDGE ST. BRIDGE
LEGEND
WAVE HEIGHT CONTOUR IN FEET
EXISTING BREAKWATER
PROPOSED BREAKWATER
STILL WATER LEVEL
ORIGIN OF COORDINATES IS TRIANGULATION STATION "SOUTH BASE" LOCATED AT THE SOUTHEAST CORNER OF NEW YORK STATE BARGE CANAL TERMINAL PIER.
NOTE: STILL WATER LEVEL = +3.5 FT LWD.
PRIMARY WAVE HEIGHT = 7.5 FT
WAVE HEIGHTS
PLAN D2: 6-SEC WAVES FROM NNW
SCALES
PROTOTYPE
MODEL

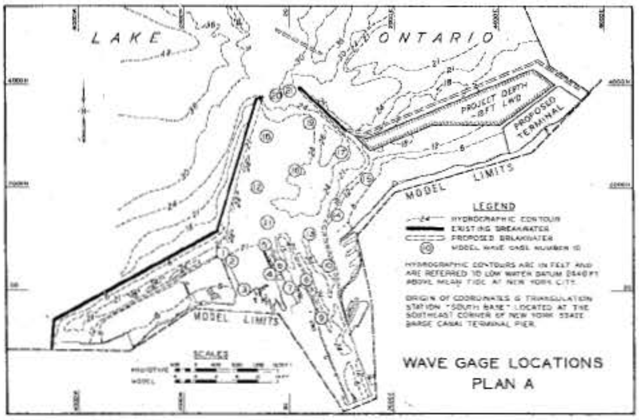
PLATE 15

PLATE 16



WAVE HEIGHTS
PLAN E: 6 SEC WAVES FROM NNW





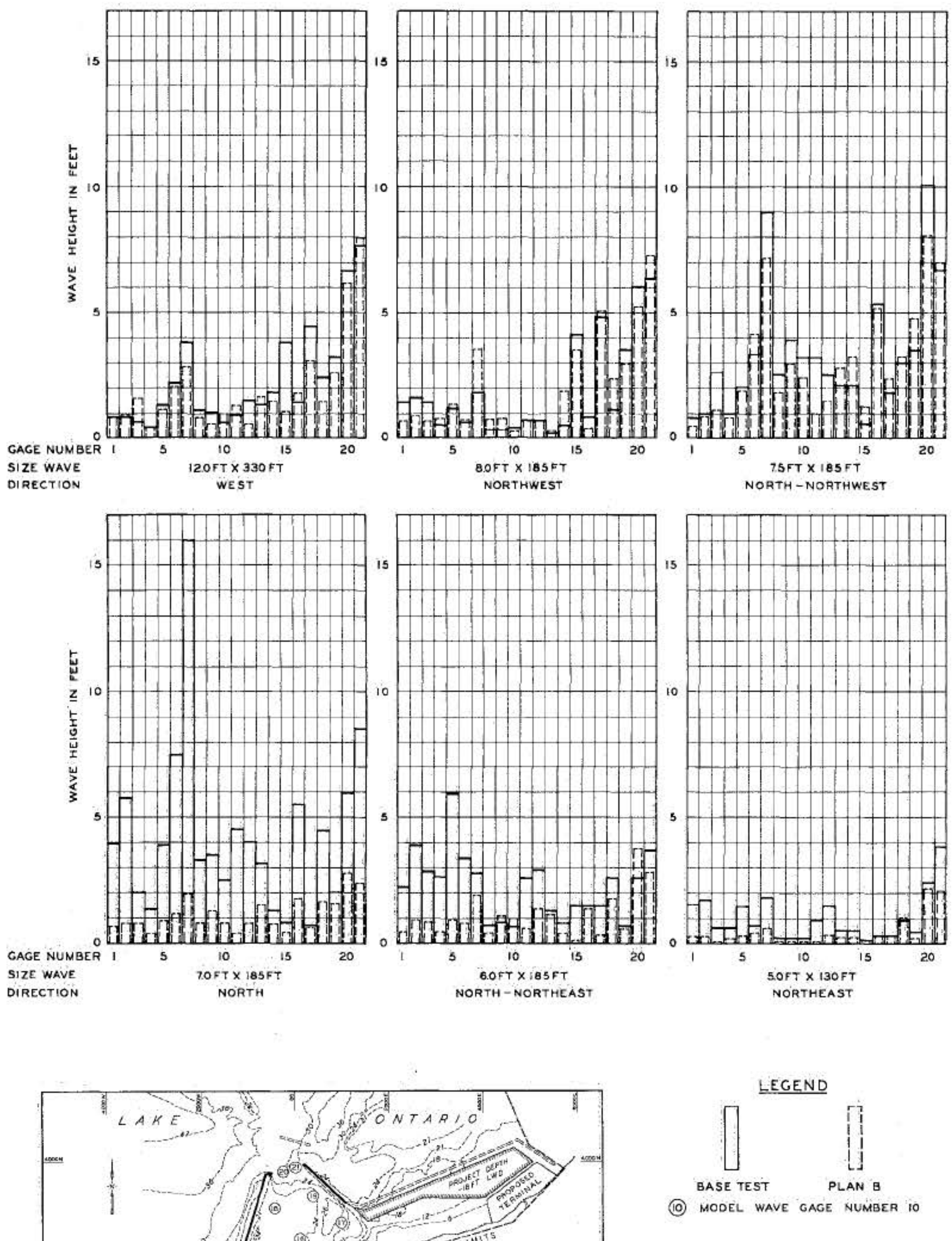
LEGEND

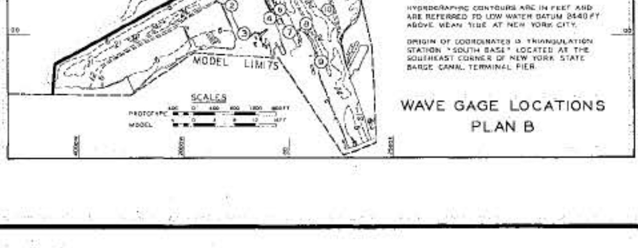
BASE TEST PLAN A

(10) MODEL WAVE GAGE NUMBER 10

COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN A





WAVE GAGE LOCATIONS
PLAN B

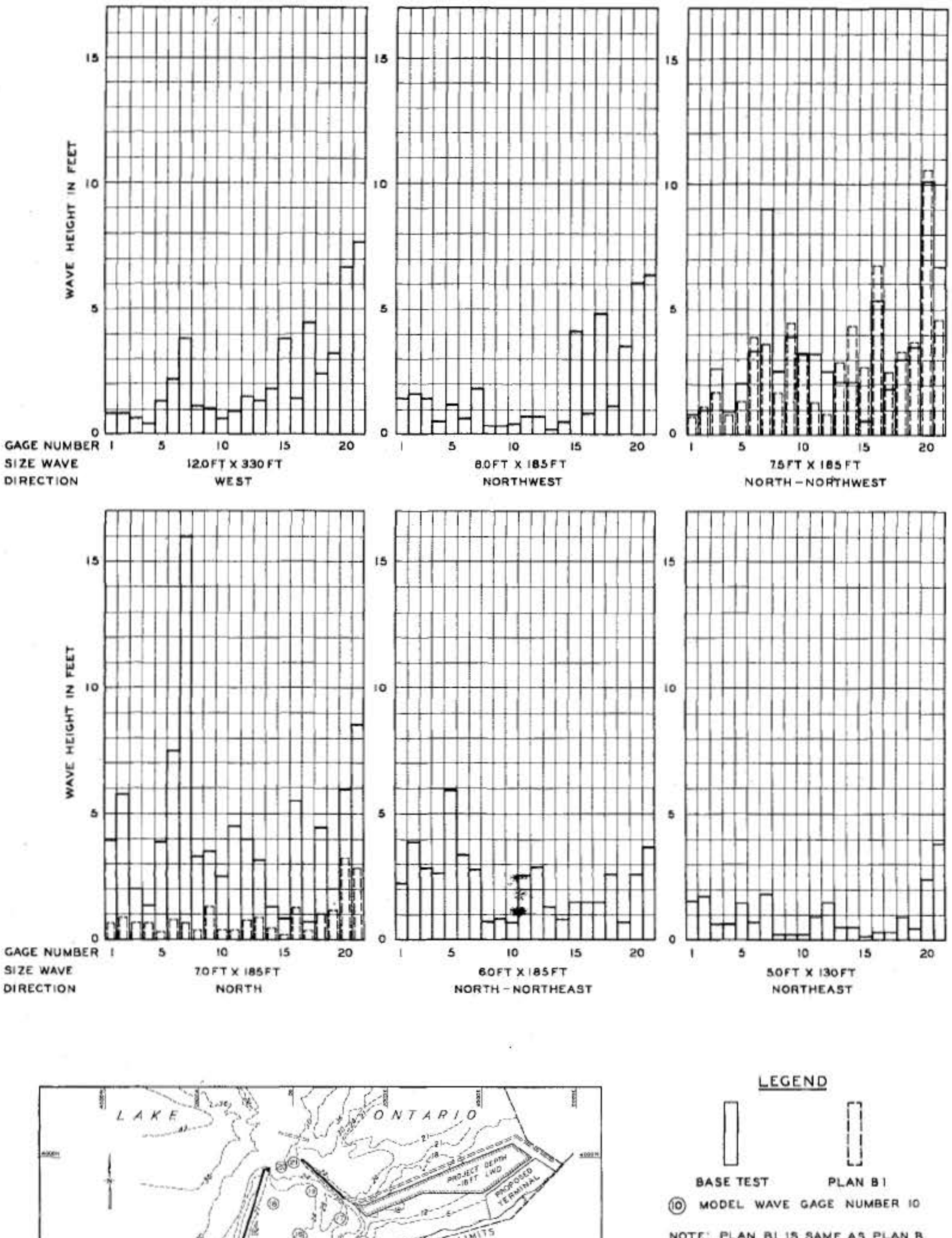
LEGEND

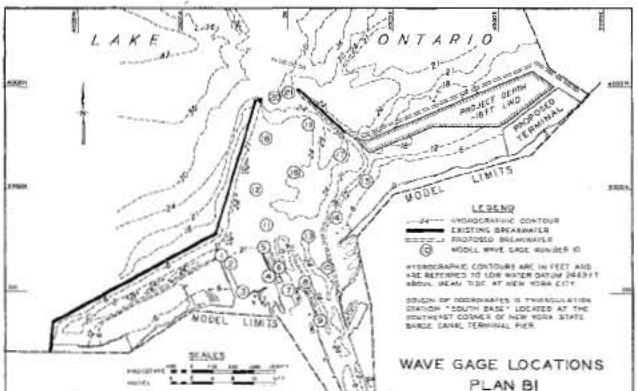
BASE TEST — PLAN B

(10) MODEL WAVE GAGE NUMBER 10

COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN B





WAVE GAGE LOCATIONS
PLAN B1

LEGEND

BASE TEST

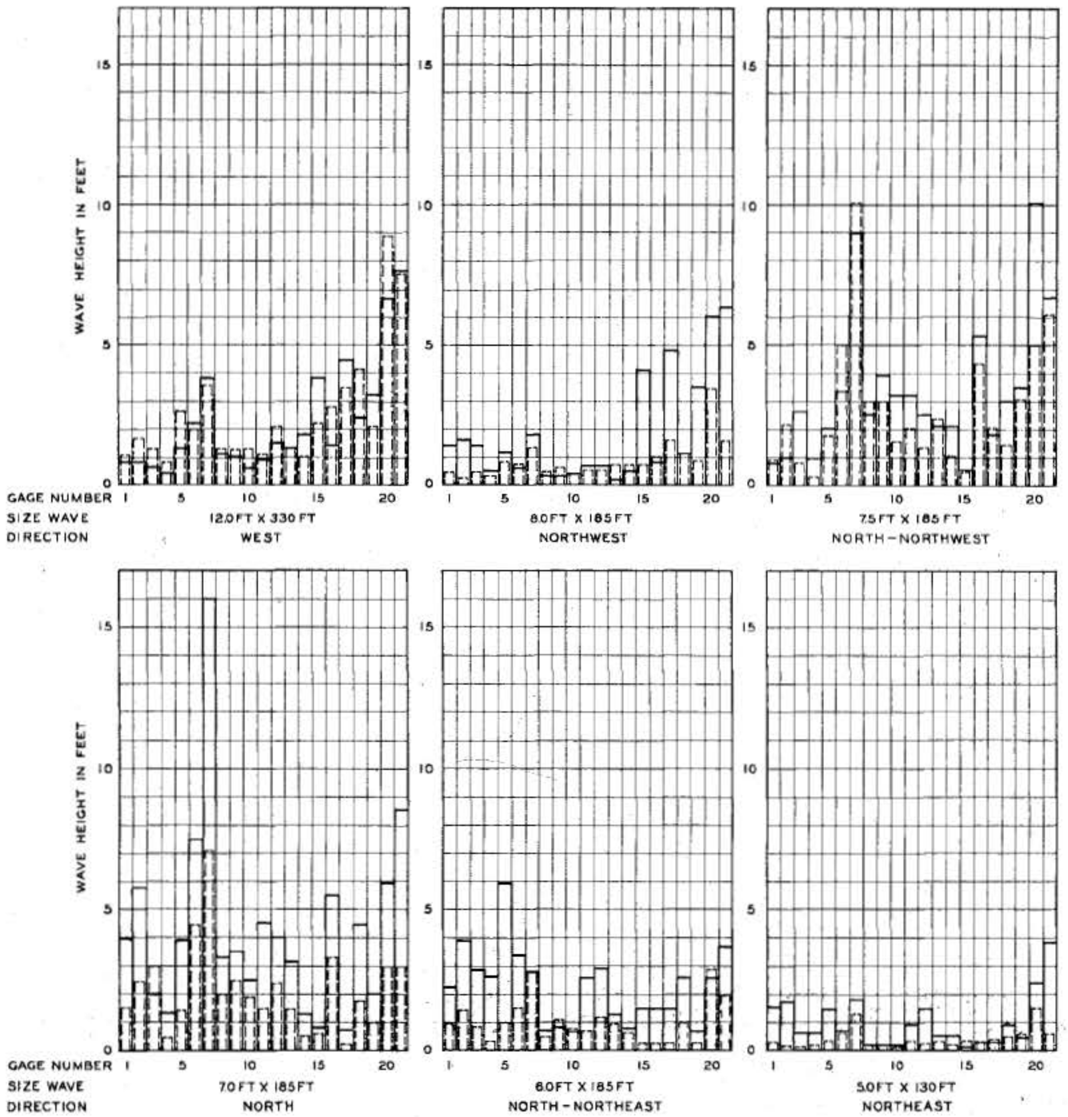
PLAN B1

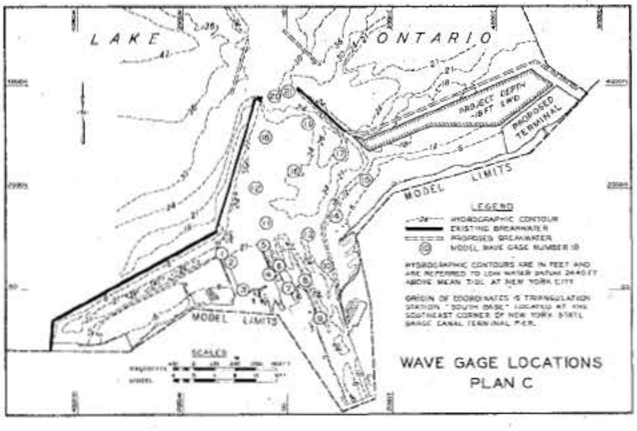
⑩ MODEL WAVE GAGE NUMBER 10

NOTE: PLAN B1 IS SAME AS PLAN B EXCEPT FOR SPENDING BEACH AT ⑦ WAVE GAGE LOCATION.

COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN B1

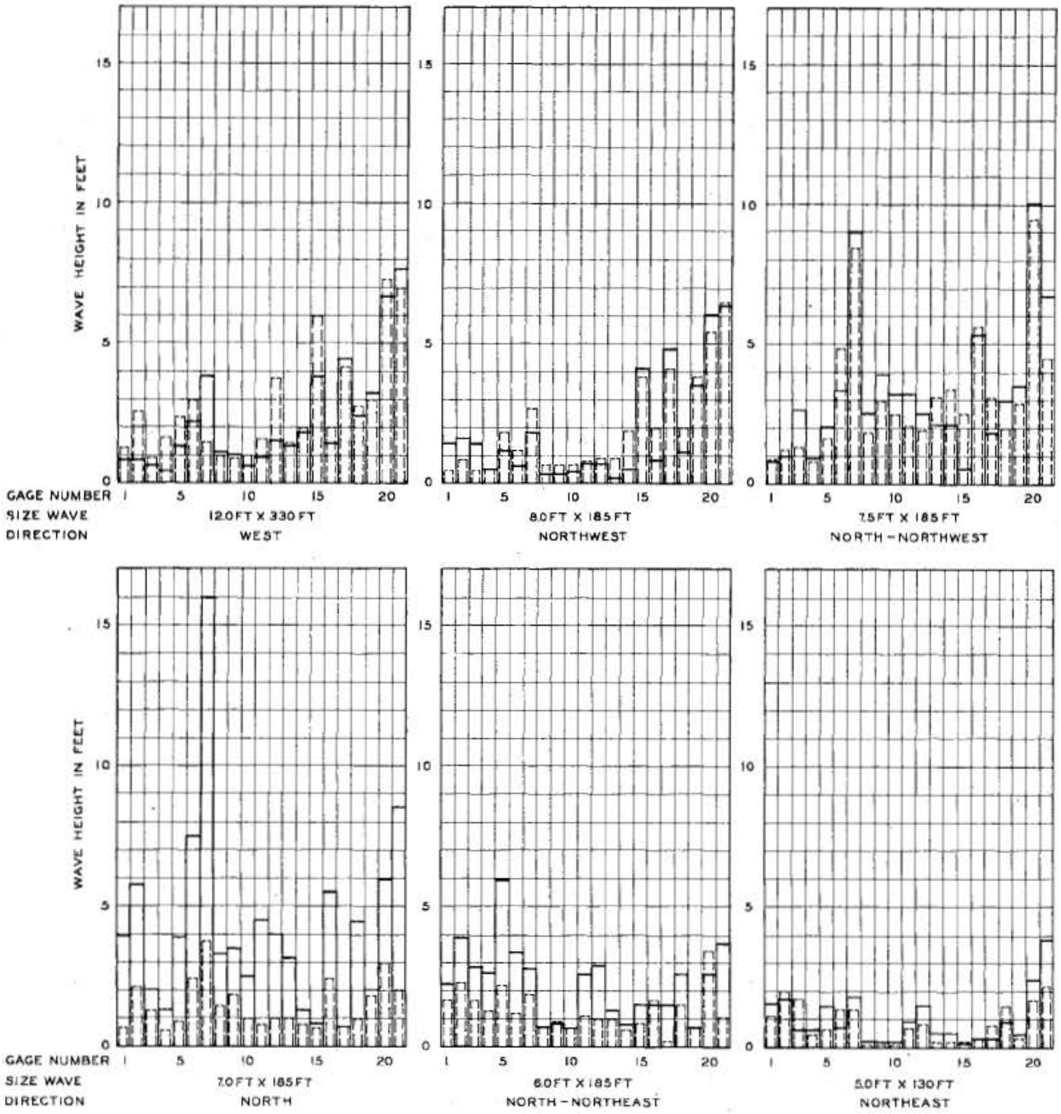


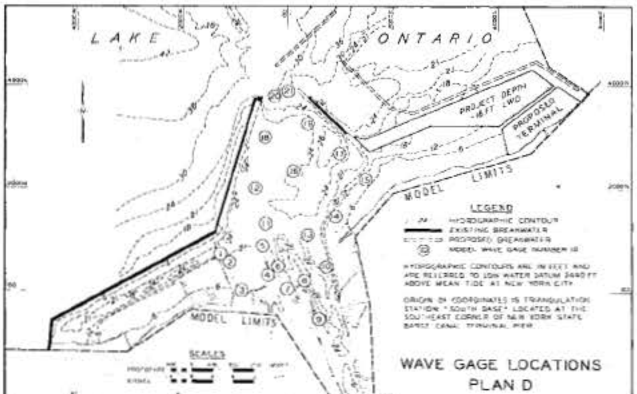


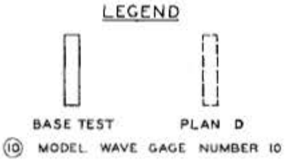
WAVE GAGE LOCATIONS
PLAN C

COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN C

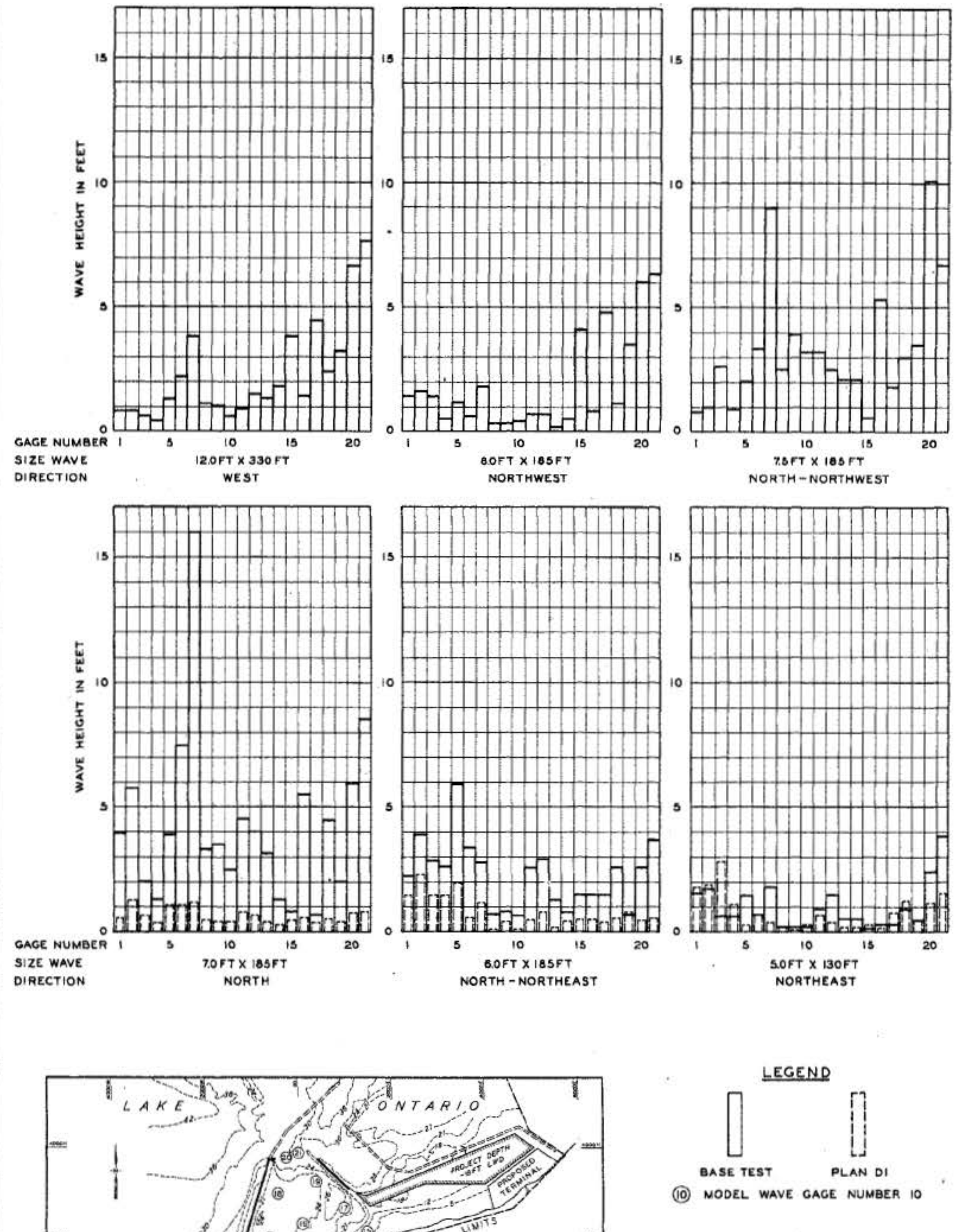


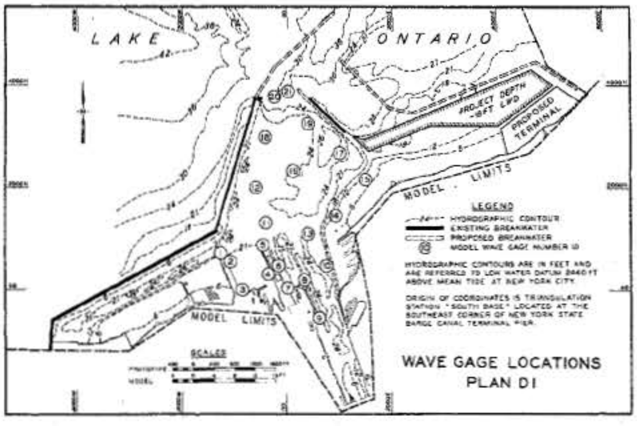




COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN D





WAVE GAGE LOCATIONS
PLAN D1

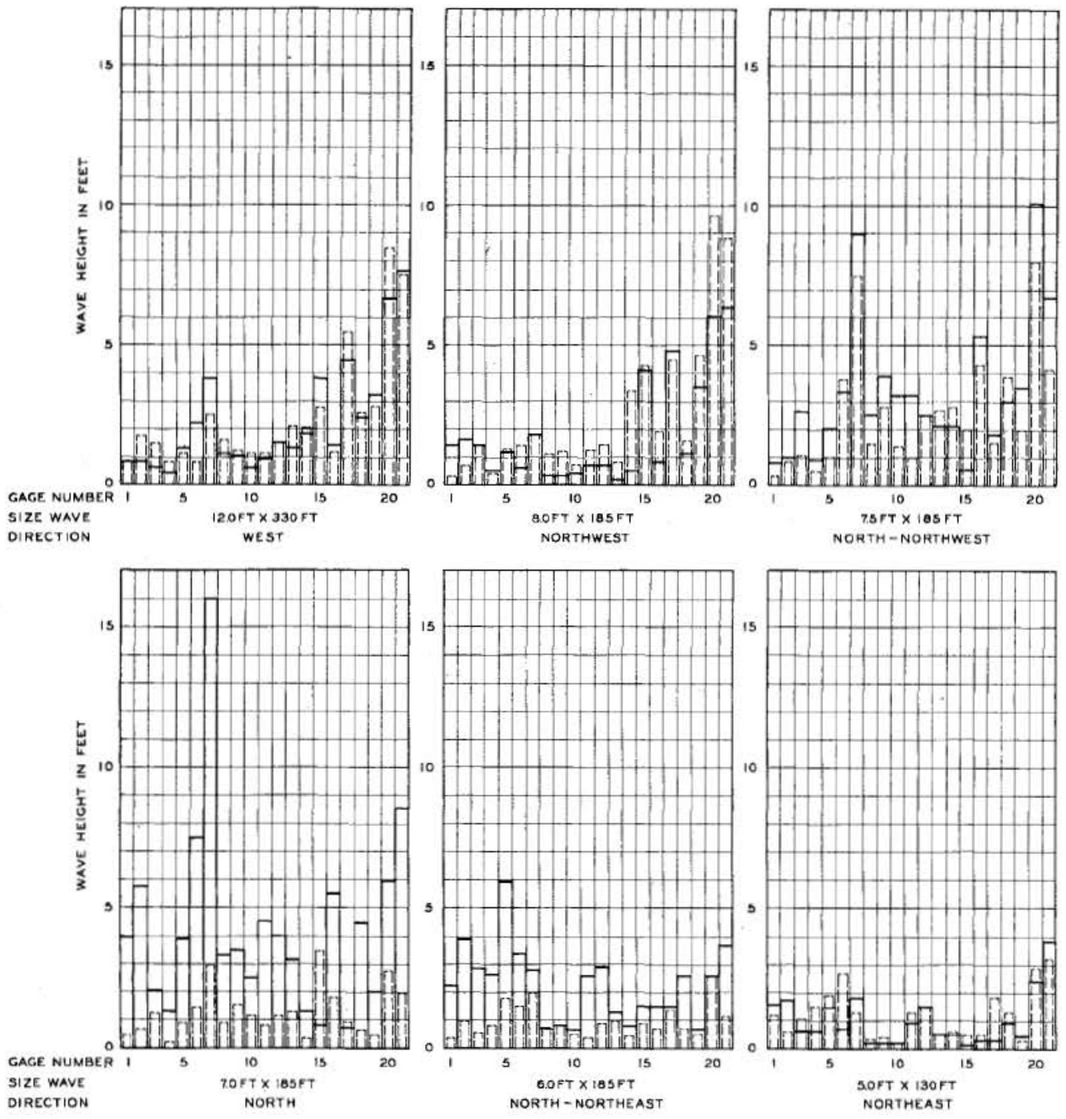
LEGEND

BASE TEST PLAN D1

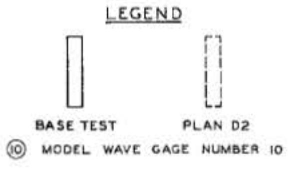
(10) MODEL WAVE GAGE NUMBER 10

COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN D1

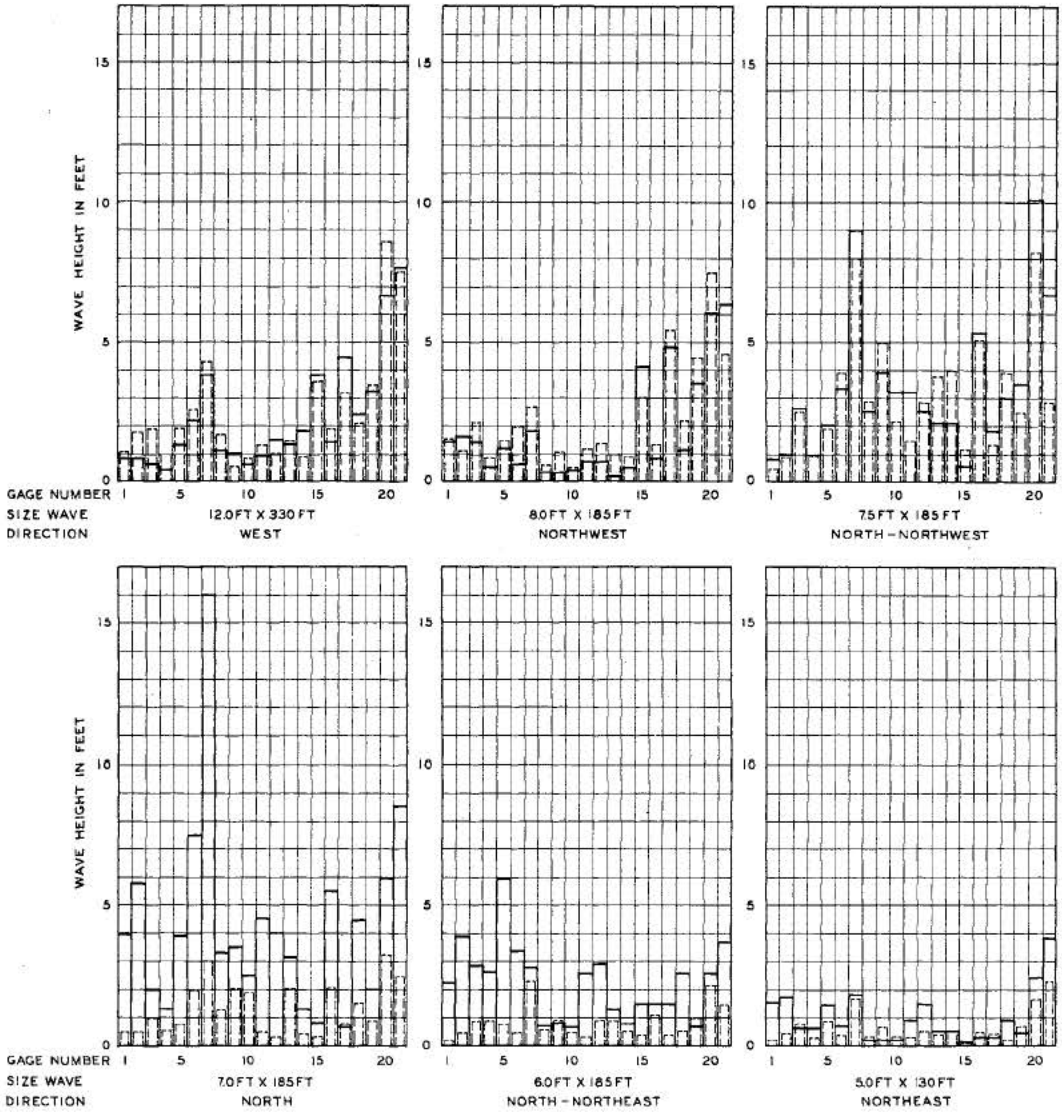


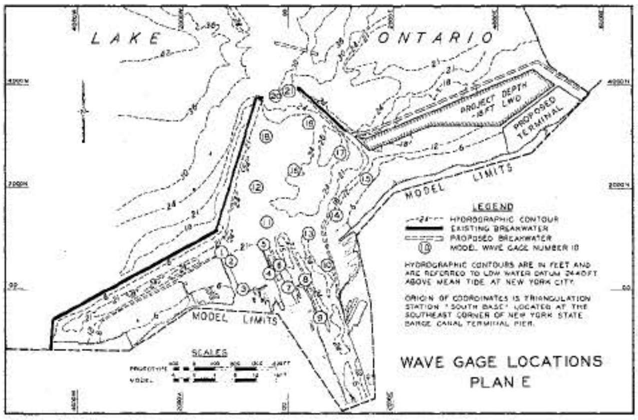
WAVE GAGE LOCATIONS
PLAN D2



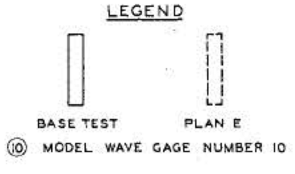
COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN D2





WAVE GAGE LOCATIONS
PLAN E



COMPARISON OF WAVE HEIGHTS

BASE TEST AND PLAN E